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THE PETROLOGY AND GEOLOGY OF A PORTION OF MALHEUR COUNTY, OREGON[1]

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ABSTRACT

Along the Owyhee River in southeastern Malheur County the rocks are of late Tertiary and Quaternary age, consisting of conglomerate, arkosic sand, and sandy shale, all derived largely from volcanic material and interbedded with volcanic tuff, basalt and, rhyolite. The stratigraphy and petrology of the igneous and sedimentary rocks are described in some detail. The structure simulates a northward-plunging anticlinal nose that has been considerably faulted, mostly parallel to the trend of the nose.

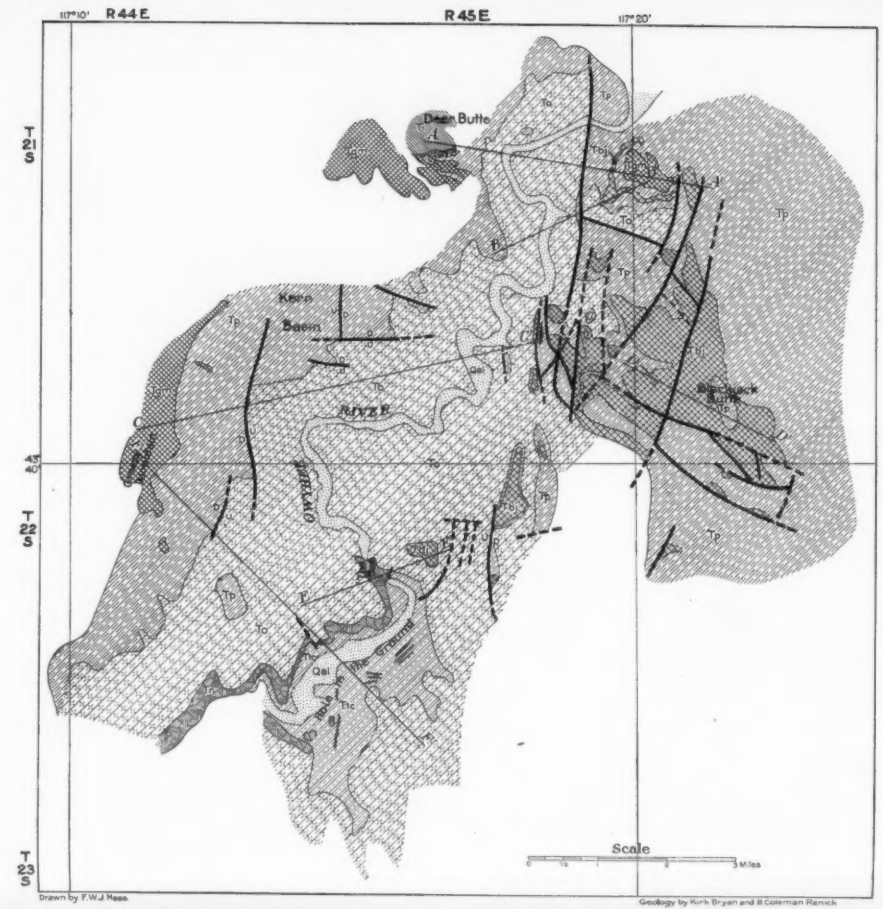
Locally the basalt flows and the sedimentary beds immediately below the flows are colored red. Also, some of the basalts contain zeolites. The cause of the red color and the origin of the zeolites are discussed, and the hypothesis is advanced that some of the flows were erupted into standing water.

INTRODUCTION AND HISTORY OF INVESTIGATION

Malheur County is in southeastern Oregon within the physiographic province known as the Columbia Plateau. The Owyhee River flows northeastward across this county through a canyon and empties into the Snake River near the town of Nyssa about 30 miles northeast on the Union Pacific Railroad. The area described in this paper embraces a strip of country about 10 miles long adjacent to the Owyhee River in T. 21+22 S., R. 44+45 E., and T. 23 S., R. 44 E. The region includes a portion of the Mitchell Butte quadrangle.

[1] Published by permission of the Director, U.S. Geological Survey.

Information obtained by Kirk Bryan has been freely used, and he has reviewed the manuscript and made numerous helpful suggestions, for all of which thanks are tendered. Clarence S. Ross has given liberal help in the petrologic study and in reviewing the manuscript. Acknowledgments for critical reading of the manuscript are due also to F. C. Calkins and B. S. Butler.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RIVER
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Tp

In 1923 Kirk Bryan, of the United States Geological Survey, made a reconnaissance examination of the area here described for the United States Reclamation Service. In October, 1924, the author spent two weeks in company with Mr. Bryan studying the geologic section and mapping the formations. This was followed by a petrologic examination of the rocks in the laboratory. A geologic report by Bryan[1] on the Owyhee reservoir and dam site has recently appeared. Although the present paper has been essentially completed

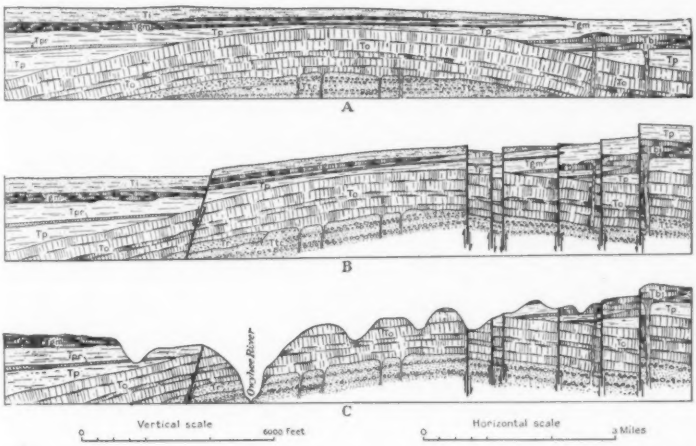

FIG. 2.—Diagrammatic sketch showing the origin of the structure and topography along the lower Owyhee River. *A*, the anticlinal structure of the Owyhee basalt with overlap of the Payette formation; *B*, same after faulting; and *C*, after erosion of the faulted terrain. *Ttc*, tuffaceous conglomerate; *Tr*, rhyolite porphyry; *Tpr*, tuff; *Tp*, Payette formation; *To*, Owyhee basalt; *Tbj*, Blackjack basalt; *Tgm*, Grassy Mountain basalt; *Ti*, Idaho formation.

for several years, publication has been delayed because of a change in the professional work of the author.

STRATIGRAPHY AND PETROLOGY

The rocks exposed in this region are shown diagrammatically in Figure 2. They are of Tertiary and Quaternary age and consist of

[1] Kirk Bryan, "Geology of Reservoir and Dam Sites with a Report on the Owyhee Irrigation Project, Oregon," *U.S. Geol Surv., Water Supply Paper 597A* (1929).

basalts, rhyolites, and sediments, the latter composed largely of material of igneous origin. The several formations shown in the accompanying geologic section are described below.

GEOLOGIC SECTION

Age		Formation	Maximum Thickness (Feet)	Lithology
Quaternary	Recent	Alluvium	50	Gravel, sand, and silt along the Owyhee River and its tributaries
	Pleistocene or Pliocene	Idaho formation	540±	Sands, silt, ash, and fine conglomerate of fluviatile, lacustrine, and subaerial origin. Contains beds of fresh-water limestone
Tertiary	Miocene	Grassy Mountain basalt	400±	Flows of massive amygdaloidal olivine basalt. Dikes also present
		Payette formation (upper part)	450±	Fluviatile, lacustrine, and subaerial deposits of sand, silt, conglomerate, volcanic ash, and tuff
		Blackjack basalt		Flows of normal augite, hypersthene, labradorite, basalt. Present east of Owyhee River
		Payette formation (lower part)	800±	
		Owyhee basalt	1300±	Flows and dikes of normal augite, hypersthene, labradorite, basalt. There are black, greenish-black, and reddish cindery varieties. Few beds of volcanic tuff interbedded
	Miocene(?)	Rhyolite porphyry	300±	Flows and dikes of porphyritic rhyolite glass. Maroon, red-brown, and black in color
		Older Tertiary sedimentary rocks	500±	Conglomerate, sand, silt, and tuff. Underlies the Owyhee basalt east of the Owyhee River and underlies the rhyolite porphyry west of the Owyhee River

TERTIARY SYSTEM

Older Tertiary sedimentary rocks.—The oldest sedimentary rocks within the region studied consist of alternating lenticular beds of partly consolidated arkosic sand, sandy shale, and conglomerate of a

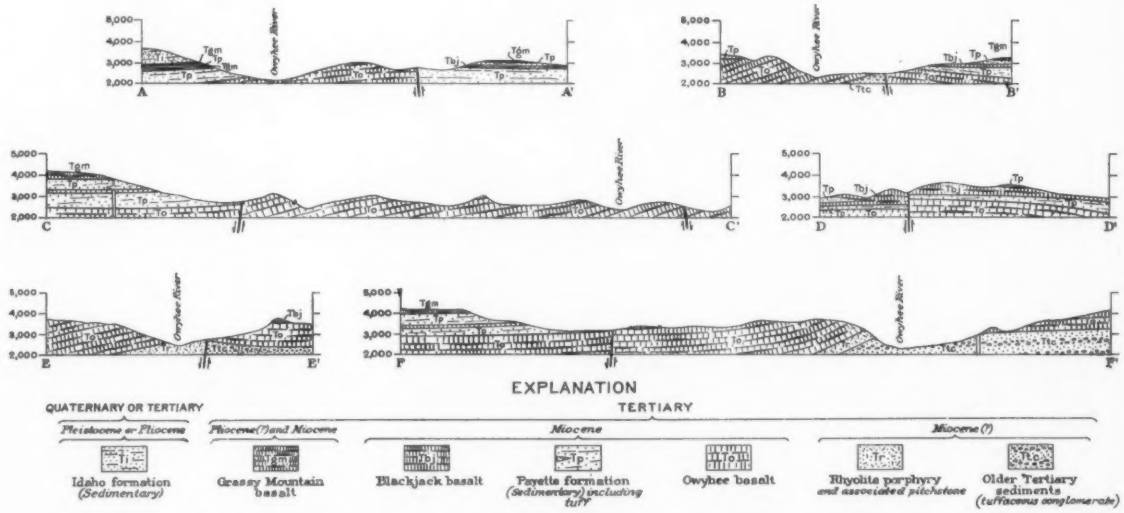

FIG. 3.—Geologic cross-section showing structure along the lower Owyhee River, Malheur County, Oregon

prevailing buff, light-brown, or green-brown color. Cobbles 6 inches in diameter are common, and a few boulders 1–2 feet in diameter were noted, but commonly the fragments are less than 6 inches and they grade to the size of sand. The pebbles usually consist of brown to dark-purple igneous rocks, whereas the sand grains are light buff or brown and therefore the conglomerate beds, in places, have a darker shade than others. These older Tertiary sedimentary rocks crop out in the Hole-in-the-Ground and in a small area near the north end of the region (see Fig. 3). The exact age of the rocks is

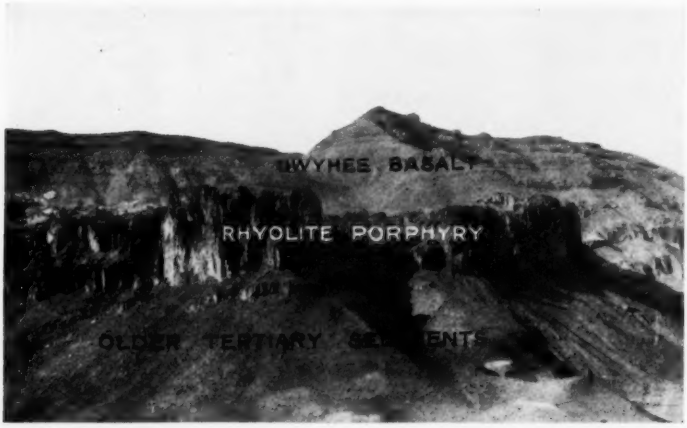

FIG. 4*A*.—Bluff west of Owyhee River at the south end of Hole-in-the-Ground showing smooth slopes underlain by the older Tertiary sediments; cliff formed by the rhyolite porphyry, and in the background the benches of Owyhee basalt. Photograph by Kirk Bryan.

undetermined. The beds will here be referred to as the older Tertiary sedimentary rocks. These sediments have been decomposed by weathering to a much greater degree than the overlying basalts or the sediments which lie above the Owyhee basalt.

There are several types of material in this sedimentary series and in so far as was practicable representative specimens of each of these types were selected for study. All contain grains of igneous rocks in all degrees of decomposition, some plagioclase feldspar, always much decomposed, and dark, claylike material.

These sedimentary rocks are cut by dikes and sills which are

mostly only a few feet thick (Fig. 4, *B* and *C*). The sediments have been metamorphosed by these dikes for a distance of about 6 inches, but the sills which are usually no thicker than the dikes have metamorphosed the overlying rocks for a distance of from 3 to 6 feet. This contact metamorphic action has resulted in an introduction of secondary silica as minute veinlets which obscure the original texture. Secondary carbonate also seems to have been added to the sediments, but it is uncertain whether or not it is genetically related

FIG. 4*B*.—East bluff along the Owyhee River in the Hole-in-the-Ground south of "The Box" showing cliffs of Owyhee basalt and complex and basalt dikes which cut the older Tertiary sediments and connect with the overlying flows of Owyhee basalt. Photograph by Kirk Bryan.

to the intrusion. These sills and dikes have partially devitrified the tuffaceous glass, which contains grains of unaltered feldspar, augite, and a small amount of quartz. Near by, and parallel to the basalt dikes, are a few small discontinuous veins consisting of calcite, dolomite, and stilbite, which indicate that water circulated through fissures at the time of or shortly after the intrusion.

These older Tertiary sedimentary rocks have probably been partially derived from a pre-Owyhee range to the east,[1] but the details

[1] W. Lindgren and N. F. Drake, "Silver City, Idaho," *U.S. Geol. Surv. Folio 104* (1904).

of the geology to the north, south, and west[1] are not sufficiently well known to preclude the possibility of the material having come as detritus from those directions. The general relations of these formations are shown with diagrammatic clearness in the canyon walls of Hole-in-the-Ground and are illustrated in Figure 4, *A* and *B*.

Rhyolite porphyry.—On the west side of Hole-in-the-Ground, outcropping as a strong cliff, there is a mass of porphyritic rock with an

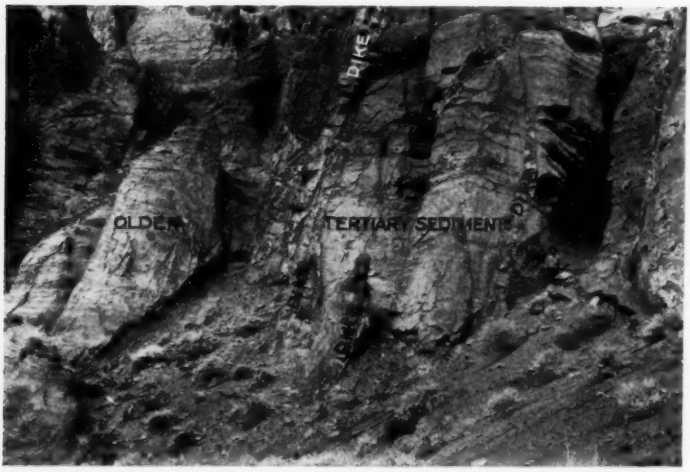

FIG. 4*C*.—Close view of the basalt dikes and intruded older Tertiary sediments shown in *B*. Photograph by Kirk Bryan.

average thickness of approximately 300 feet (map, Fig. 1). It dips west-northwest at an angle of 15° or less, and it is here a lava flow lying on the older Tertiary sedimentary rocks and overlaid by the Owyhee basalt. At the north end of Hole-in-the-Ground where this porphyry crosses the Owyhee River it is much thicker, and is there probably in part intrusive. At this locality, because of its high resistance to erosion, the Owyhee River has been able to cut only a very

[1] I. C. Russell, "A Geological Reconnaissance in Southern Oregon," *Fourth Ann. Rept., U.S. Geol. Surv.* (1884), pp. 431–64; "Notes on the Geology of Southwestern Idaho and Southeastern Oregon," *U.S. Geol. Surv. Bull. 217* (1903); "A Preliminary Report on Artesian Basins in Southwestern Oregon," *U.S. Geol. Surv. Water Supply Paper 78* (1903).

narrow gorge through the porphyry. This gorge is known as the "Box," and it is here that the location of a dam is proposed.

At the Box and along the west bluff of Hole-in-the-Ground most of the rock is a massive, aphanitic, red felsite porphyry with colorless phenocrysts. This rock is glassy and brittle and breaks with a conchoidal fracture. Much of it has a banded flow structure and is also fractured in vertical, horizontal, and intermediate systems. At the top, and in places at the bottom, the felsite grades into pitchstone agglomerate, which consists of a matrix of white tuffaceous material in which are fragments of black glass ranging from sizes less than 1 inch in diameter up to many feet. In hand specimens phenocrysts of feldspar can be seen in both the black pitchstones and the red rock. Along the contact of these two rock types within 2 or 3 feet there are all gradations from the red felsite to the black glass, and from both into the white comminuted glass or tuff. In some places the rock texture consists of alternate bands of the red felsite porphyry and black pitchstone. Many of the pitchstone fragments in the agglomerate above the contact show, especially on the weathered surface, a crenulated and contorted flow texture indicating movement after the banded flow texture developed and before complete consolidation. Cutting the red felsite are small dikes and sheets which are identical with the fragments of the agglomerate. These pitchstone dikes are more numerous near the upper part of the red felsite. At the base of the massive flows west of Hole-in-the-Ground and lying between the pitchstone agglomerate and the red felsite there is a breccia of angular to subangular fragments of red porphyritic felsite with less numerous pitchstone fragments, all in a matrix of red felsite.

Bryan[1] has described the megascopic features of the porphyry and its several phases in considerable detail, and has also discussed the mode of origin of the rock. Microscopic examination of the red porphyritic rock and the black phyritic pitchstone shows that both have a glassy groundmass. In the groundmass lie phenocrysts of calcic andesine with an average composition of about $Ab_{45}An_{55}$ and a much smaller quantity of a highly birefracting mineral that seems to be augite. Many slides do not show quartz, but a very few small phenocrysts are present. The average length of the andesine feldspar phe-

[1] Bryan, *op. cit.*, pp. 44–52.

nocrysts is about 0.5 mm., and that of the augite grains about 0.01 mm.

In the glassy groundmass of this rock there is a considerable amount of microcrystalline calcic feldspar, but other minerals, if present, are indistinguishable. Figure 5, *B*, shows the typical pitchstone phase; Figure 5, *C*, shows the red porphyritic phase; and Figure 5, *A*, is a type intermediate between these two. The groundmass of the pitchstone phase of the rock (Fig. 5, *A*) consists of crenulated glass with alternating light- and dark-colored bands, and with high-power magnification a perlitic texture is apparent.

Figure 5, *C*, is a photomicrograph of a thin section of the red felsite. In this specimen there is no flow structure and the feldspars are very irregularly oriented; the glassy groundmass is dark red-brown. In most slides the groundmass is light buff to light brown, and the darker color of this specimen has been produced by weathering. High magnification of this red porphyritic rock shows that in addition to the abundant larger andesine and less abundant augite phenocrysts there is a second generation of exceedingly small microlites.

Although this porphyritic red rock as seen in the field has the habit of a rhyolite, its appearance under the microscope is rather that of a latite, and most thin sections do not show any quartz though it is sparingly present. A sample of the typical porphyritic red rock was analyzed by J. R. Fairchild. The norm calculated from this analysis shows that the rock falls into Class I, Order 4, Rang 2, Subrang 3, and should be classed as a rhyolite. The high silica, the absence of identifiable quartz and orthoclase, and the presence of the high calcium feldspar (andesine) are unusual in a rock that chemical analysis indicates as a rhyolite. Evidently the groundmass is high in silica and potassium.

Partial analysis of a composite of several samples of the red porphyritic rhyolite near the north end of Hole-in-the-Ground along lower Owyhee River appears on the following page.

At the south end of Hole-in-the-Ground the continuation of this flow of rhyolite crosses the Owyhee River and outcrops in the south bluff but there most of it is not red but a dense black rock. North-

east of this locality, less than $\frac{1}{4}$ mile, there are dikes and sills of a black rock which appears to be akin to the black phase of the rhyolite in the southeast bluff and which looks like a glassy basalt. Microscopic examination of the black rock at the south end of Hole-in-the-Ground shows that it contains a generation of large plagioclase

PARTIAL ANALYSIS OF RED PORPHYRITIC RHYOLITE

	Per Cent
SiO_2*	71.71
Al_2O_3	14.49
Fe_2O_3	2.01
FeO	0.30
MgO	0.25
CaO	2.35
Na_2O	3.84
K_2O	4.06
TiO_2	0.25
Sum	99.26

Calculated Norm†	Per Cent
Quartz	28.80
Orthoclase	23.91
Albite	32.49
Anorthite	10.29
Diopside	1.08
Hypersthene	0.10
Magnetite	0.23
Hematite	1.92
Ilmenite	0.46
Sum	99.28

* J. G. Fairchild, analyst.
† Class 1, Order 4, Rang 2, Subrang 3.

phenocrysts with a composition of about $Ab_{50}An_{50}$ and a lesser amount of augite phenocrysts both in a groundmass which consists of aggregates of very small feldspar and pyroxene phenocrysts and glass, the smaller generation of crystals having apparently just begun to crystallize out of the glass. Figure 5, *D*, shows that the degree of crystallization in this rock is intermediate between the porphyritic rhyolite (Fig. 5, *C*) and the normal porphyritic Owyhee basalt

A

B

C

D

FIG. 5.—For explanation, see page 493

EXPLANATION OF FIGURES 5–8, 10

FIG. 5.—Photomicrographs of thin sections of rhyolite porphyry, associated pitchstone, and related rocks at Hole-in-the-Ground. *A*, gradational phase between pitchstone and rhyolite porphyry. One nicol. *B*, typical pitchstone at Hole-in-the-Ground. One nicol. *C*, typical rhyolite porphyry at Hole-in-the-Ground. One nicol. *D*, dark-colored basic andesite (?) at south end of Hole-in-the-Ground. One nicol. *Au*, augite; *Gl*, glass; *Mg*, magnetite; *Pl*, plagioclase (from basic andesine to labradorite).

FIG. 6.—Photomicrographs of thin section of Owyhee basalt and Blackjack basalt. *A*, typical crystalline Blackjack basalt; microporphyritic with large phenocrysts of labradorite and augite and a second generation of smaller labradorite crystals. Groundmass of augite and microcrystalline feldspar, accessory magnetite. Microscopically it is not essentially different from the crystalline varieties of the Owyhee basalt. *B*, typical crystalline Owyhee basalt, microporphyritic with large phenocrysts of labradorite and augite (and some hypersthene) and a smaller generation of labradorite. Groundmass of augite and microcrystalline feldspar, accessory magnetite. Microscopically similar to the Blackjack basalt, *A*. *C*, typical glassy amygdaloidal Owyhee basalt. The groundmass is red glass and the vesicles are filled with carbonate and zeolites. *D*, dike of Owyhee basalt cutting pre-Owyhee sediments at Hole-in-the-Ground. Labradorite, augite, and hypersthene and accessory magnetite. Note absence of large feldspar phenocrysts and the rudely parallel orientation of the feldspars which correspond to the "second generation" feldspars in the microporphyritic basalt, *A* and *B*. *Pl*, plagioclase; *Au*, augite; *C*, carbonate; *Z*, zeolites.

FIG. 7.—*A*, coarse-grained basalt at top of Owyhee basalt. Consists of basic plagioclase (labradorite), hypersthene, and augite. The groundmass of this rock has been altered to a red color, but the rock is not weathered as may be seen by comparing it with *B*, which is fresh. *B*, fresh coarse-grained basalt at top of Owyhee basalt. Consists of labradorite, hypersthene, and augite. *C*, volcanic tuff at the base of the Owyhee basalt (interval 9, section 1). *D*, volcanic ash showing gas bubbles from interval 4, Deer Butte section 3. *Pl*, plagioclase (mostly basic labradorite); *Py*, pyroxene (hypersthene predominant and augite); *Gl*, glass; *Li*, lithic fragments; *V*, vitric fragments; *Ib*, basic igneous rock grain; *B*, gas bubbles.

FIG. 8.—Photomicrographs of thin sections of some sediments. *A*, coarse-grained sandstone of Payette formation, 3 of section 2. Nicols crossed. *B*, conglomerate (1) at top of Deer Butte, section 3. One nicol. *C*, fresh-water limestone (3) Deer Butte, section 3. One nicol. The elliptical bands are shells. *D*, coarse-grained sandstone of Payette formation 6 of section 2. One nicol. *Ar*, arkose; *C*, carbonate; *I*, igneous rock; *Pl*, plagioclase; *Or*, orthoclase; *Q*, quartz; *Qu*, quartzite; *Sh*, carbonate shells.

FIG. 10.—Photomicrographs of thin sections of the Grassy Mountain basalt. *A*, typical fresh olivine basalt near top of Grassy Mountain showing phenocryst of olivine in a groundmass of basic bytownite, augite, and magnetite. *B*, showing typical diabasic texture of the Grassy Mountain basalt. The groundmass consists of bytownite, augite (some hypersthene), and magnetite. *C*, amygdaloidal facies of Grassy Mountain basalt from near top of interval 9 in the Deer Butte section 3. Shows the vesicles lined with chlorite and the center filled with carbonate. The groundmass of the rock is altered. *D*, amygdaloidal facies of Grassy Mountain basalt from interval 9 in Deer Butte section 3. Shows laths of plagioclase in a groundmass in which all of the augite and olivine has been decomposed (presumably pneumatolytically or hydrothermally). Many of the cavities are lined with chlorite and carbonate. *C*, carbonate; *Ch*, chlorite; *Ov*, olivine; *Py*, pyroxene (mostly augite but with some hypersthene); *Pl*, plagioclase (mostly basic bytownite); *Gm*, groundmass; *Mg*, magnetite.

(Fig. 6, *B*). It is probable that the composition is intermediate between the rhyolite and the basalt and is a basic andesite.

Owyhee basalt.—In the bluffs along the Owyhee River there is exposed a series of basalt flows aggregating about 1,300 feet in thickness to which the name of Owyhee basalt was applied. The Owyhee basalt is composed largely of thin lava flows averaging less than 40 feet in thickness, but dikes are numerous and sills form an important part of the whole mass. At least one-third of the total thickness consists of very scoriaceous lava and cinder beds which range in color from bright red to purple and give to the mass as a whole a red or red-brown color. The following section was measured at Hole-in-the-Ground, beds 1–5 being measured in the west bluff and beds 6–9 in the east bluff. In general each flow is massive at the base, where it is gray to blackish and grades up into more scoriaceous material which is usually red, in many places the flow culminating at the top in a reddish-purple clinker, cinders, or tuff. The dikes and sills are massive throughout.

At the locality where the sections were made, and at other places, a relatively small amount of tuffaceous material is interbedded with these basalts. The tuff bed 9 at the base of the section overlies the older Tertiary sediments on the east side of Hole-in-the-Ground and overlies the rhyolite porphyry on the west side of Hole-in-the-Ground. The tuff bed 5 is persistent in the vicinity of Hole-in-the-Ground. It thus appears that, although the Owyhee basalt was mainly a product of fissure eruptions, a part of it was erupted explosively from vents, which presumably lay along fissures that had become partially clogged.

Except for the 15-foot tuff bed (5 of sec. 1), which is well exposed on each side of Hole-in-the-Ground, distinctive markers are scarce or wanting within these basalts.

At the top of the Owyhee basalt there are several flows which have an aggregate thickness of about 200 feet and which are generally dark gray in color and contain lath-shaped plagioclase feldspar crystals that are easily recognized in hand specimens. Locally portions of these flows are reddish and coarse grained; this characteristic is more specifically mentioned in the consideration of the petrology. This coarse-grained eruptive at the top of the Owyhee basalt is of considerable utility as an index bed in working out the faults east of

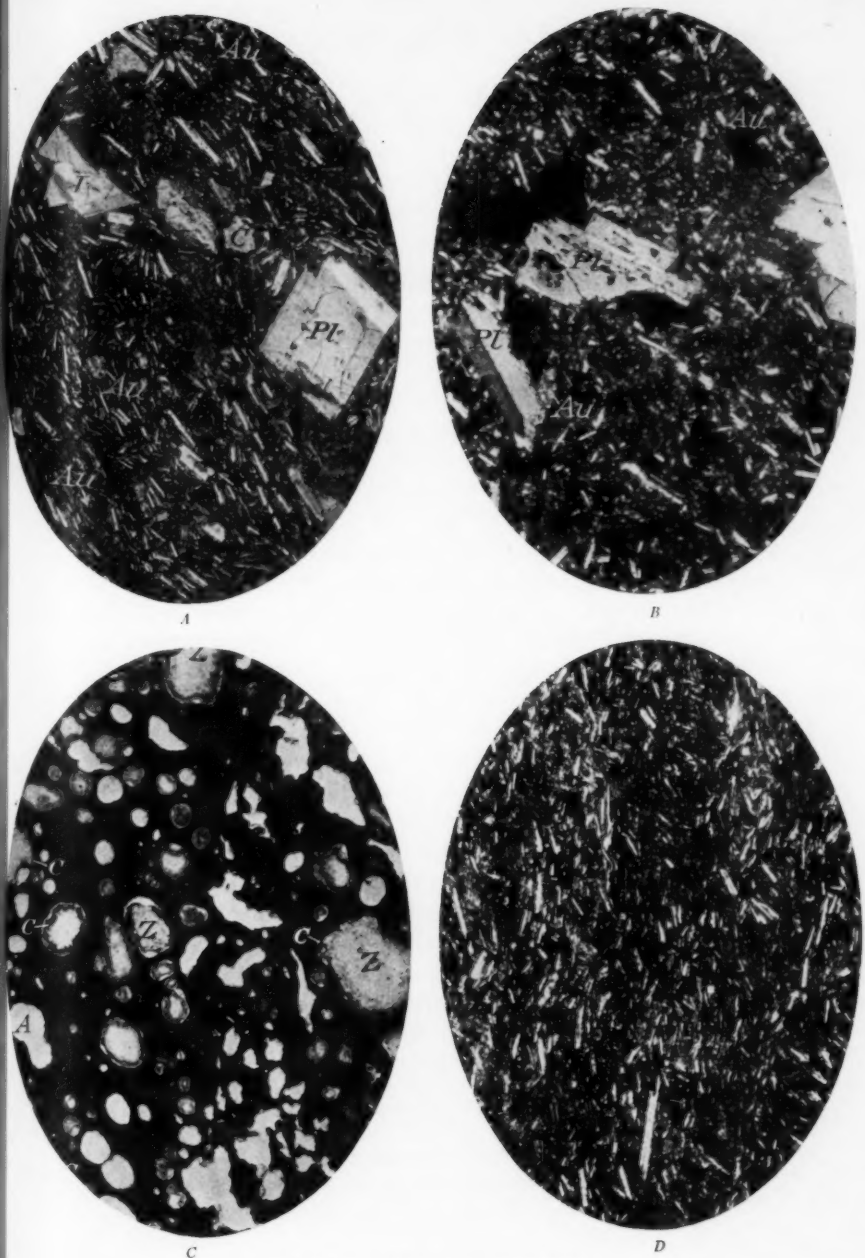

FIG. 6.—For explanation, see page 493

the Owyhee River, as it is generally easy to distinguish it in the field from the overlying Blackjack basalt and from the underlying beds of Owyhee basalt, both of which are ordinarily much finer in texture.

The flows of Owyhee basalt of the area were all erupted within the period during which the great mass of basalt flows known as the Columbia River basalt were outpoured to the north, and the perhaps

SECTION 1

OWYHEE BASALT AND ASSOCIATED SEDIMENTS AT HOLE-IN-THE-GROUND

Base of Payette formation: Description	Thickness Feet
Top of older Tertiary sediments	
Owyhee basalt:	
1. Coarse-grained basalt containing large feldspar crystals	210
2. Mostly massive gray basalt but including considerable scoriaceous basalt and cinders. Includes a few beds of red-and-white tuff	133
3. Dark-colored flows of basalt with dark-red scoriaceous and cindery-top varieties	420
4. Gray basalt; cinders at top	163
5. Tuffaceous conglomerate; red at top	15
6. Massive gray and black basalt, scoriaceous and cindery at the top; few lenses of tuffaceous sediment; maximum thickness of 4 feet	182
7. Black, brown, purple, and red basalt, largely scoriaceous and cindery	136
8. Concealed; probably tuff	22
9. Volcanic tuff	27
Total thickness	1,308

smaller mass of basalt known as the Snake River basalt was erupted in this general region. The flows of the Columbia River basalt are said to range in age from Eocene to possibly Pliocene, as shown by the fossils contained in the separating sediments.[1] The Snake River basalt includes flows of Tertiary and probably of Quarternary age, but is regarded as probably chiefly of Pliocene age.[2]

[1] I. C. Russell, "A Preliminary Paper on the Geology of the Cascade Mountains in Northern Washington," *U.S. Geol. Surv., Twentieth Ann. Rept.*, Part II (1900), pp. 129–34; G. O. Smith, "Ellensburg, Washington," *U.S. Geol. Surv. Geologic Folio 86* (1903); G. O. Smith and F. C. Calkins, "Snoqualmie, Washington," *U.S. Geol. Surv. Geologic Folio 139* (1906).

[2] I. C. Russell, "Geology and Water Resources of the Snake River Plains of Idaho," *U.S. Geol. Surv. Bull. 199* (1902); J. B. Umpleby, "Geology and Ore Deposits of the Macay Region, Idaho," *U.S. Geol. Surv. Prof. Paper 97* (1917).

The Owyhee basalt is older than the Blackjack basalt and younger than the above-mentioned rhyolite porphyry, upon which it rests. It is considered to be equivalent to a basalt occurring in the adjacent quadrangle[1] to the east which Lindgren first tentatively referred to as the Eocene but later considered as Miocene.

Le Conte[2] pointed out long ago that most of the basalts of the Columbia River Plateau were the result of fissure eruptions, and since then most of the great basalt eruptions of Miocene age in the northwest have been attributed to this type of volcanism. These Owyhee lavas seem to be of similar origin, as numerous feeder dikes extend up through the underlying older Tertiary sediments and connect with basalt sills and flows above.

Microscopic examination of the Owyhee basalt (Fig. 6) excluding the coarsely crystalline basalts (interval 1 of sec. 1) at the top of the formation (see Fig. 7, *A* and *B*) shows that the crystalline varieties have as their principal constituents plagioclase feldspar determined as calcic labradorite with an average composition of $Ab_{35}An_{65}$; augite is also abundant in most sections; hypersthene is commonly present; and magnetite is the principal accessory mineral. In texture the crystalline varieties of these basalts are microporphyritic, containing a generation of large crystals (Fig. 6, *B*). The largest labradorite grains have a maximum dimension of 1.6×0.5 mm., and an average of about 0.5×0.15 mm.; the largest augite crystals are generally smaller than this. Besides this earlier generation of large feldspar crystals there is a gradation to a smaller crystal and there are also feldspar crystals, presumably younger, whose average length is about 0.2 mm. and which generally have a tendency toward parallel orientation.

In these crystalline basalts the groundmass is generally microcrystalline feldspar and pyroxene with disseminated magnetite. Magnetite occurs also as included crystals in both the feldspar and the augite phenocripts and in such relationship is fresh and unaltered. The relative proportions of feldspar and pyroxene vary in dif-

[1] W. Lindgren and N. F. Drake, "Nampa, Idaho-Oregon," *U.S. Geol. Surv. Geol. Folio 103* (1904); "Silver City, Idaho," *U.S. Geol. Surv. Geol. Folio 104* (1904).

[2] J. le Conte, "On the Great Lava Flood of the Northwest" and "On the Structure and Age of the Cascade Mountains," *Amer. Jour. Sci.* (3d ser., 1874), pp. 167–80, 250–67.

FIG. 7.—For explanation, see page 493

ferent flows, but a fair average for the series is approximately labradorite ± 60 per cent; pyroxene (augite and hypersthene) ± 35 per cent; and magnetite ± 5 per cent. Calcite is present as a secondary constituent in varying amounts. A brilliant red, highly birefracting material noted in some slides is probably iron-stained pyroxene. A yellowish mineral with fairly high birefringence which was noted in some slides is probably iron-rich beidellite.[1]

Figure 6, *D*, is a photomicrograph of a thin section of one of the typical dikes which cuts the older Tertiary sediments (see Fig. 4, *B*), which represents a feeder to the overlying Owyhee basalt. Though mineralogically similar, this rock differs in texture from the overlying basaltic flows with which it is genetically related. The most important constituent of the dike rock is labradorite as bladed crystals. These feldspars vary considerably in size, but there is apparently only one generation with an average length of about 0.2 mm. Augite and magnetite occupy the interstitial space. A greenish material occurs as fair-sized aggregates or is disseminated through the rock. This mineral, which seems to represent an alteration product of augite, has a γ index of about 1.557, and according to Ross[2] is probably chlorite.

The red vesicular and more rarely lavender-tinted upper part of the flows possesses a groundmass of brilliant brick red and an exceedingly fine-grained crystalline aggregate consisting largely of hematite and of small lathlike crystals, doubtless plagioclase. Large phenocrysts of labradorite and pyroxene are also present. Many of the vesicles are filled with a zeolite (Fig. 6, *C*). According to Clarence S. Ross: "This zeolite in the Owyhee basalt has the following optical properties: $\alpha = 1.492$; $\beta = 1.495$; $\gamma = 1.449$, optical character +, axial angle near 90° and angle of extinction small. These properties indicate that the mineral is heulandite."

The distinctive coarse-grained basalt at the top of the Owyhee basalt, referred to above and represented by the interval 1 in section 1, is illustrated by the photomicrographs (Fig. 7, *A* and *B*). The

[1] E. S. Larsen and E. T. Wherry, "Beidellite, a New Mineral Name," *Jour. Wash. Acad. Sci.*, Vol. XV (1925), pp. 465–66; C. S. Ross and E. V. Shannon, "The Chemical Composition and Optical Properties of Beidellite," *ibid.*, pp. 467–68.

[2] C. S. Ross, personal communication.

most important constituent is labradorite ($Ab_{35}An_{65}$). There are about equal portions of augite and hypersthene, and magnetite is the principal accessory. In the feldspar phenocrysts carlsbad and albite twinning are well displayed. The average size of the large feldspar crystals is about 1.3 × 0.3 mm., and the maximum length about 2.7 mm. The groundmass of this rock is microcrystalline and contains aggregates of small plagioclase crystals which in any small area are essentially parallel. The average size of these smaller crystals is about 0.2 × 0.01 mm.

The red color characteristic of some parts of the Owyhee basalt is found on microscopic examination to be due to the presence of hematite, which is confined entirely to the groundmass. Figure 7, *A*, is a photomicrograph of a thin section of the red rock, and Figure 7, *B*, is a photomicrograph of the unaltered dark rock. It is apparent from these illustrations that the rocks are almost identical in every respect but color.

It is an interesting fact that the Owyhee basalt along the lower Owyhee River does not contain olivine. Lindgren and Drake[1] report that the thick series of basalts to the east, which are considered to be of the same general age, in some places contain olivine and in other places do not contain that mineral. The Miocene Yakima basalt of central Washington,[2] the Columbia River basalt[3] in the Columbia River gorge, and the Columbia River basalt of the John Day basin[4] are all olivine basalts.

The persistent tuff bed in the bluffs on each side of Hole-in-the-Ground (9 of sec. 1) consists of a combination of vitric crystals and lithic constituents (Fig. 7, *C*), and, like the lavas above and below, seems to be basaltic. The interstitial material between grains and the vitric fragments are weathered to a greenish color, which is probably due to the presence of chlorite. Individual vitric grains are also

[1] Lindgren and Drake, *op. cit.*

[2] G. O. Smith, "Geologic Atlas of the United States: Ellensburg," *U.S. Geol. Surv. Folio 86* (1903); "Geologic Atlas of the United States: Mount Stuart, Washington," *U.S. Geol. Surv. Folio 106* (1904); Smith and Calkins, *op. cit.*

[3] I. C. Williams, "The Columbia River Gorge, Its Geologic History," *Mineral Resources of Oregon*, Vol. II, No. 3 (1916).

[4] F. C. Calkins, "A Contribution to the Petrography of the John Day Basin," *U. of Calif. Pub.*, Vol. III, p. 159.

stained green but not to as great an extent as the groundmass. Some of the glass fragments are quite fresh.

Payette formation.—Overlying the coarse-grained basalt at the top of the Owyhee basalt and below the Grassy Mountain basalt there are sedimentary beds which, on the basis of stratigraphic position and lithology, are correlated with the lower part of the Payette formation of Lindgren and Drake.[1] The question of the age of the Payette formation has been recently discussed by Knowlton[2] and Buwalda.[3] Knowlton agrees with the conclusion reached by Chaney[4] that the Payette flora is Miocene. The Payette in this region is probably in part the stratigraphic equivalent of the Mascall formation referred to the Miocene by Merriam,[5] Sinclair,[6] and Chaney.[7]

Section 2 is composed largely of light-colored, little-cemented sand, sandy shale, ash, tuff, and conglomerate. These beds are mostly cream colored to light yellow with shades of buff and green in places. The tuff bed (7) is easily recognized on the west side of Owyhee River, where it is a useful key bed, but it was not found on the east side of the river, and its correlative there is probably the Blackjack basalt, which occurs at about the same stratigraphic position.

It is believed that the light-colored sands (8) and (9) at the base of the Payette formation were deposited in a body of standing water, as they are evenly bedded sediments resembling lake deposits. It is probable that the lower part of tuff (7) was deposited as showers of ash in water, and since the bed is 125 feet thick it may have com-

[1] Lindgren and Drake, *op. cit.*

[2] F. H. Knowlton, "Flora of the Latah Formation of Spokane, Washington, and Cœur d'Alene, Idaho," *U.S. Geol. Surv. Prof. Paper 140* (1926), pp. 18–19.

[3] J. P. Buwalda, "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *Science* (N.S., 1924), Vol. LX, pp. 572–73.

[4] R. W. Chaney, "Notes on the Flora of the Payette Formation," *Amer. Jour. Sci.* (5th ser., 1922), Vol. IV, pp. 214–22.

[5] J. C. Merriam, "A Contribution to the Geology of the John Day Basin," *Univ. Calif. Bull., Dept of Geol.*, Vol. II, No. 9 (1901), pp. 269–314.

[6] J. C. Merriam and W. J. Sinclair, "Tertiary Faunas of the John Day Region," *ibid.*, Vol. V, No. 11 (1907), pp. 171–205.

[7] R. W. Chaney, "The Mascall Flora—Its Distribution and Climatic Relation," *Carnegie Inst. of Wash. Pub. 349*, pp. 23–48.

pletely filled this body of water. Unlike the tuff, which lies as it fell, the material of the overlying bed (6) consists of re-worked material derived in part from the tuff (7), and its uneven lamination is suggestive of stream deposition.

SECTION 2

PAYETTE FORMATION AND ASSOCIATED BASALT FLOWS ON THE WEST SIDE OF THE OWYHEE RIVER; ALSO POSSIBLY INCLUDES SOME YOUNGER BEDS*

DESCRIPTION	THICKNESS Feet
Top of Grassy Mountain mesa:	
Grassy Mountain basalt:	
1. Blackish green rock locally grading up into red and lavender color	205
Payette formation:	
2. Fine-grained white-to-buff ashy sediment with a gradation near the top from a lavender-tinted to a red rock at the contact with the overlying basalt	67
3. Massive coarse-grained, whitish sandstone	7
4. White ashy silt	57
5. Fairly coarse, little-cemented sand, mostly white but partly buff with a few red stains	170
6. Massive coarse-bedded sandstone consisting largely of re-worked volcanic material; at the base there is a conglomerate of volcanic material derived partially from the underlying tuff	25
7. Tuff, gray	125
8. Alternating beds of white-and-buff sands and sandstone with beds of shaly sand	130
9. Mostly concealed; consists of light-colored shaly sands mostly buff and pale-green colored	225
Total thickness of Payette formation	806

* Section measured about 3¼ miles south-southwest of Kern basin, and about 2¼ miles south of B.M. 2711, Mitchell Butte quadrangle.

Near the end of Payette time sedimentation was interrupted by the earlier extrusions of the Grassy Mountain basalt and by ash showers (4) and (2). The possibility of some of the flows having been deposited in water is discussed on a subsequent page.

Thin sections of the sandstone (6) overlying the tuff bed show that it consists mostly of grains of quartz, orthoclase, and altered igneous rock grains which are mostly basalts (see Fig. 8, *D*). The grains of this rock range between 2.5 and 0.3 mm. in size. A few grains of pla-

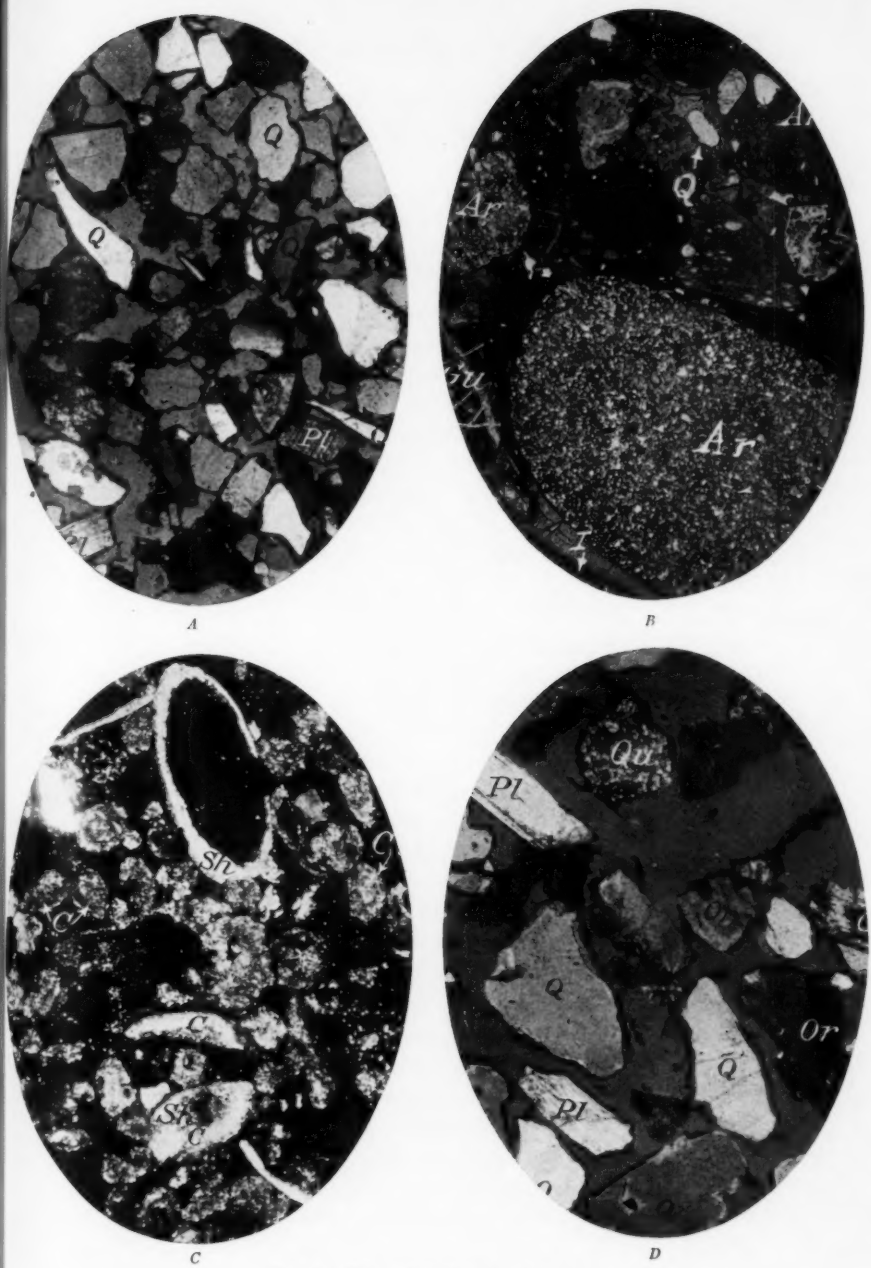

FIG 8.—For explanation, see page 493

gioclase and microcline were observed. The orthoclase is partially altered to carbonate and white mica, and the basalt fragments are much decomposed.

A thin section of the material in interval 7, section 2, shows that it is a typical volcanic ash consisting mostly of glass and feldspar. The edges of the glass grains have been altered to a clay mineral that resembles beidellite. Microscopic examination of the coarse-grained sandstone (3), section 2, shows that it is composed largely of angular and subangular quartz grains. Plagioclase feldspar is next in importance (see Fig. 8, *A*). White mica is enclosed in and adheres to some of the feldspar grains and probably represents a primary mineral of the igneous rock from which the feldspar is derived. There also may be a small amount of secondary muscovite. Much of the plagioclase (and possibly some orthoclase which seems to be present) have been partially altered to carbonate. There are also a few rounded grains of quartzite and carbonate.

Blackjack basalt.—In the vicinity of Blackjack Butte a series of basalt flows occur within the Payette formation. The center of outflow of these basalts is in the general vicinity of Blackjack Butte, where they attain a maximum thickness of between 350 and 450 feet. From this maximum the thickness apparently decreases eastward toward the Snake River and westward toward the Owyhee River. The interval between the Owyhee basalt and the Blackjack basalt decreases both westward and southward, being not more than 25 feet at some places near the westernmost outcrop of the Blackjack basalt, and at several localities along the bluff at the southeast end of Hole-in-the-Ground the Blackjack basalt apparently rests directly on the Owyhee basalt. East of Blackjack Butte, however, in the bluff west of the Snake River at least 700 feet of sediment underlies the Blackjack basalt and the top of the Owyhee basalt is not exposed.

Weathered outcrops generally have a rough, dark-brown surface but some flows are red and the rock is usually vesicular. The Blackjack basalt generally has a banding texture both in the vesicular and the non-vesicular types; when such is the case, the lithology serves to identify it as a flow of Blackjack basalt. The bands which are rudely parallel with the top of the flow are defined by the arrangement of the vesicles where these are present and in the case of the non-vesicular types probably represent planes along which the vol-

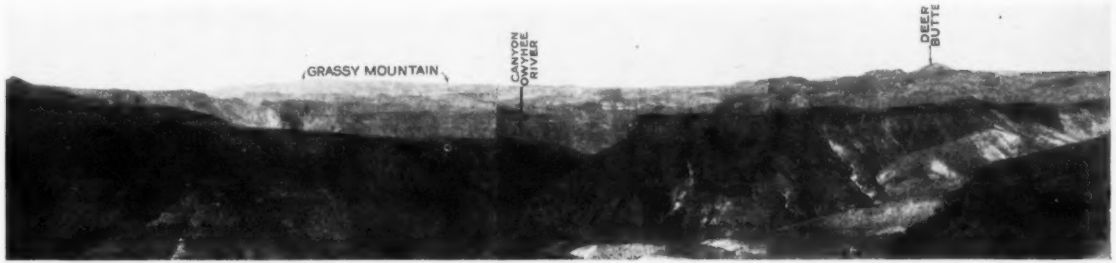

FIG. 9*A*.—View west from a point about 1½ miles northwest of Blackjack Butte (showing the rough topography of country). The canyon in the middle foreground is a tributary to the Owyhee River. The top of the west bluff of the Owyhee may be seen in the middle distance. Photograph by Kirk Bryan.

FIG. 9*B*.—West bluff of the Owyhee River about 2½ miles east of Kern Basin. Owyhee basalt forms the bluff adjacent to the river. Photograph by Kirk Bryan.

canic gases accumulated in the denser type. In the massive basalt the bands are lighter in color than the associated rock. The vesicles in the Blackjack basalt have not been filled up so as to form amygdules, but they are often lined with a thin deposit of carbonate or a secondary green mineral (chlorite?).

The Blackjack basalt is believed to have been extruded largely through fissures, but not entirely so since there are two cinder cones which rest on this lava about 3 miles northwest of Blackjack Butte. The presence of the cinder cones or craters lends support to the suggestion that the thick tuff bed below the Grassy Mountain basalt on the west side of the Owyhee River (interval of 7 of sec. 2 and Fig. 3) may be correlated with the Blackjack basalt and record a time of explosive volcanic activity in the latter part of the Blackjack epoch.

On microscopic examination the Blackjack basalt is found to be similar if not almost identical with the Owyhee basalt. The Blackjack basalt is illustrated by Figure 6, *A*, and the Owyhee basalt by Figure 6, *B*; the microscopic similarity of these two basalts is apparent.

The Blackjack basalt contains feldspar phenocrysts with a maximum size of 1.3×0.55 mm. and an average size of 0.8×0.3 mm. A smaller generation of feldspar phenocrysts average about 0.2 mm. in length (Fig. 6, *A*). Augite phenocrysts attain a maximum size of 0.5 mm. in diameter, but a larger portion of the augite crystals are between 0.5 and 0.2 mm. in length.

Grassy Mountain basalt.—The sedimentary beds assigned to the Payette formation are overlaid by and in part interbedded with flows of basalt, no one of which is more than 200 feet thick, and which, as a whole, may reach an aggregate thickness of 400 feet. This basalt caps Grassy Mountain and is here named the Grassy Mountain basalt. Numerous outcrops show that it extends continuously from Grassy Mountain to the vicinity of Deer Butte and for an unknown distance north and south. On the south slope of Deer Butte, where section 3 was measured, a basalt flow is overlaid by about 50 feet or more of Payette beds and is therefore lower stratigraphically than the main part of the Grassy Mountain basalt, but it is considered, because of its petrographic character, to be a member of the Grassy Mountain rather than the Blackjack basalt.

The Grassy Mountain basalt contains olivine as an essential constituent, and in this respect it is unique since it is the only rock in the area in which olivine was found. As observed in the hand specimen, this basalt is generally massive but contains amygdules that are generally completely filled with carbonate. In color, most of the rock approaches black with a faint greenish tint. However, in places the usual dark color grades into a reddish or red-brown color with here and there purple tints; areas of this reddish type of rock are often an acre or more in extent. The reddish portions have also red-brown phenocrysts that are visible in hand specimens. A different phase of this basalt was observed in a ravine at the south end of Deer Butte, where it is also amygdaloidal, but the amygdules contain a green mineral (see interval 9, sec. 3), and the rock as a whole resembles a pebble bed. Ross and Shannon[1] have illustrated an amygdaloidal andesite that very much resembles this phase of the Grassy Mountain basalt. At a number of places in the Kern basin and on the east slope of Grassy Mountain dikes cut the sediments below the Grassy Mountain basalt and connect with the flows.

Microscopic examination of the Grassy Mountain basalt shows that the texture of the groundmass is diabasic-ophitic (Fig. 10, *A*) and that it contains phenocrysts of olivine averaging about 2 × 1.2 mm. in a groundmass of plagioclase and augite with some hypersthene and minor amounts of magnetite. The phenocrysts of olivine, one of which is shown in Figure 10, *A*, are commonly well developed but frequently they have been partially or entirely altered to iddingsite although the outline of the original grain of olivine is commonly still distinct. Not only is this basalt distinctive because of the presence of olivine, but the feldspars are basic bytownite with an average composition of about $Ab_{25}An_{75}$. Approximately 50 per cent of the rock is composed of this basic feldspar, the crystals of which are about 0.3 mm. long.

The reddish or purplish phase of the rock, a type which is common in Grassy Mountain, is similar to the gray rock except that the olivine crystals, some of the pyroxene, and part of the groundmass of the rock have been altered to an undetermined reddish material,

[1] C. S. Ross and E. V. Shannon, "Nordenite and Associated Minerals from near Challis, Custer County, Idaho," *Proc. U.S. Nat. Museum*, Vol. LXIV (1924), Pl. 2.

FIG. 10.—For explanation, see page 493

doubtless colored by ferric iron. The vesicles in the Grassy Mountain basalt are filled with carbonate and a zeolite. According to Clarence S. Ross: "The zeolite in the Grassy Mountain basalt possesses the following optical properties: $\alpha = 1.495$, $\beta = 1.494$, $\gamma = 1.502$, optical character +, axial angle small and angle of extinction small. The mineral is therefore heulandite."

Thin sections of the amygdaloidal basalt (9, sec. 3) near the base of the Deer Butte section show that the green mineral lining vesicles has an index of approximately 1.64, an estimated birefringence of 0.02 and that the mineral is probably chlorite (see Fig. 10, *C* and *D*). The material filling the center of the cavities, which appears to be later than the chlorite, is carbonate. In this rock the feldspars though easily distinguishable are considerably altered, and the pyroxene is almost completely altered to this greenish mineral. Olivine is present, but the diabasic texture characteristic of the great mass of Grassy Mountain basalt is not present in this amygdaloidal phase.

Idaho formation.—The Grassy Mountain basalt is overlaid by the youngest sedimentary rocks exposed in the area mapped. They are believed to belong to the Idaho formation of Cope,[1] which is now regarded as of Pliocene or Pleistocene age. The beds outcropping in Deer Butte and, as measured in section 3, on the southwest face of the Butte are 544 feet thick. Near the base of the Deer Butte section two beds of ashy silt are interbedded with the Grassy Mountain basalt and another overlies it (see 6, 8, and 10 of sec. 3). These beds have an aggregate thickness of about 170 feet, are thinly laminated, and are light gray to white with a greenish hue. Their fine grain and delicate lamination suggest that they may be lake deposits.

The succeeding 219 feet (interval 5, sec. 3) consists of interbedded conglomerate, sandstone, and sandy silt. The conglomerate and sandstone beds are generally firmly indurated. The pebbles in the conglomerate consist of siliceous rock, basalt, and various weathered igneous rocks. Many of them have a green coating which probably consists of chlorite. Near the top of these beds there is more sand than conglomerate, and it grades upward into the ash bed of member 4, which is about 100 feet thick. This ash bed grades upward

[1] E. D. Cope, *Acad. Nat. Sci., Philadelphia Proc.* (1883), p. 138.

into some light-yellow siliceous fresh-water limestone beds containing small shells (interval 3).

The conglomerate (5) of the 219-foot interval consists of a rather heterogeneous assemblage. The pebbles, the largest of which are about 10 mm. in diameter, consist of the following types of material: quartzite with veinlets of secondary quartz; altered arkose, a decomposed igneous rock which is probably a rhyolite with phenocrysts of

SECTION 3

SECTION OF IDAHO FORMATION AND ASSOCIATED BASALT FLOWS IN DEER BUTTE

DESCRIPTION	THICKNESS Feet	
Idaho formation:		
1. Massive conglomerate, very resistant to erosion; weathered brown	11	
2. Sandstone, white, fine grained	27	
3. Limestone—light-buff-yellow argillaceous, fossiliferous	80	
4. Massive fine-grained volcanic ash	100	
5. Interbedded sandy silt, sandstone, and massive fine lenticular conglomerate	219	
6. White ashy sandy silts, gray tinged with green and pale yellow, in some bands	107	
Total thickness		544 544
Grassy Mountain basalt and interbedded strata of Payette formation:		
7. Grassy Mountain basalt (olivine basalt)	87	
8. Thin-bedded white ashy silts tinted pale green	50	
9. Grassy Mountain basalt, scoriaceous at the top	35	
10. Thin-bedded silts, top 2 feet; baked red by overlying basalt	13	
Total thickness		185 729

quartz and of feldspar, the latter having a parallel orientation; and basalt decomposed except for the feldspars. Besides these larger grains the conglomerate contains small grains of quartz, quartzite, feldspar, arkose, and basalt averaging about 0.3 mm. in diameter, and isolated crystals of green hornblende and white mica. The finer matrix is considerably altered and indeterminate, but a large part of it is highly birefracting yellow mineral that may be beidellite.

The sandstone beds of interval 1 contain grains of quartz, usually

optically strained, plagioclase (mostly bytownite with included apatite crystals), quartzite, slightly altered arkosic material, and also various kinds of weathered igneous rock. The quartz and feldspar grains are about equal in number to the other grains. The quartzite and arkosic grains average about 0.1 – 0.05 mm. in diameter, and both, especially the quartzite, are cut by veinlets of secondary silica.

The fine-grained volcanic ash of the 100-foot intervals (4) contains grains of volcanic glass, quartz, and plagioclase, named in the order of relative abundance. The glass has been largely altered to a clay-like mineral which resembles beidellite. A few crystals of zircon, biotite, and hornblende were also noted. It also contains many perfectly preserved gas bubbles with an elongation in one direction which makes them resemble a cross-section of a dipper with a handle (see Fig. 7, *D*). Since these bubbles were formed during the fall of the ash it is probable that the material has been re-worked by water or air very little if at all.

The fresh-water limestone, 3 of section 3 (Fig. 8, *C*), as seen in thin sections, consists almost wholly of irregular-shaped granules of carbonate, but perhaps 5 per cent of it is made up of other constituents consisting mostly of quartz and plagioclase (labradorite and bytownite). The fossil shells referred to below appear as the circular and elliptical forms in Figure 8, *C*.

The sandstone (2) appears megascopically to be very similar to the sandstone (5). The conglomerate which caps Deer Butte (1 of sec. 3) is similar to the conglomerate within interval (5), described above. The pebbles are well rounded, ranging in size from 10 to 2 mm. and averaging about 3 mm. (Fig. 8, *B*).

The evidence regarding the age of the beds here referred to the Idaho formation is meager. A small sample of the fresh-water limestone (3) containing some shells was referred to W. H. Dall, of the United States National Museum, who states: "It contains few fossils and these are represented by internal casts which seem to indicate (besides some minute cypridean Crustacea) a species of *Pompholyx*. This genus extends from the Pliocene to Recent time, and gives no clue to the age of the deposit other than it is not older than Pliocene and the probabilities are that it is younger."

It is unlikely that there are beds younger than Pleistocene in this butte, so that the fossil evidence, as far as it goes, tends to support correlation of the beds with the Idaho formation, which is now generally considered to be of Pliocene or Pleistocene age.

The boundary between the Payette and the Idaho formations is arbitrarily drawn at the top of the Grassy Mountain basalt, though it is recognized that the beds of interval 6, sec. 3, accumulated during the same general conditions of sedimentation as the beds of intervals 8 and 10, and that the former may belong to the Payette formation. In this connection it is interesting to note that in the Bruneau basin to the east Piper[1] reports an olivine basalt at the bottom of the Pliocene section.

QUATERNARY SYSTEM

It is possible that some of the sediments in Deer Butte that are referred to the Idaho formation are of Pleistocene age and that a considerable part of geologic section 3 may be of that age, the Idaho formation being now generally regarded as of Pliocene or Pleistocene age. The Quaternary system is also represented in the area by discontinuous terrace gravels and by Recent alluvium deposited in the valleys of the existing streams. The gravels, sands, and silts are derived from the nearby sedimentary and volcanic formations.

ORIGIN OF RED COLOR OF THE ROCKS AND POSSIBLE ERUPTION OF SOME OF THE BASALTS INTO WATER

Introductory statement.—Observations were made in the field which suggested that some of the basalts of this region had been poured into water, and subsequent microscopic study of the basalts and the associated sediments lends support to this hypothesis.

Grassy Mountain basalt.—The sedimentary beds immediately below the Grassy Mountain basalt are baked red through an interval of from 2 to 4 feet. This red color grades downward through a pale-lavender color into the original cream or light gray of the Payette beds within a distance of 2 feet. The red color as shown by microscopic examination is due largely to the formation of ferric iron oxide in the interstitial material.

[1] A. M. Piper, "Geology and Water Resources of the Bruneau River Basin, Owyhee County, Idaho," *Idaho Bureau of Mines Pamphlet 11* (1924).

Change of color or other alteration at the base of lava flows is rare, and in many places flows pass over a surface with almost no heat effect on the underlying material even if it is of a combustible nature.[1]

The suggestion is here offered that part of the Grassy Mountain basalt was probably poured out into a body of water, such as a lake or pond, or possibly on to a playa or river flood plain (with its associated lagoons and estuaries). The sediments at the bottom of such a body of water necessarily contained water and some air, and the water when heated by the basalt would be converted into steam. This steam and air, along with the other gases given off from the cooling lava, would cause much more active oxidation than dry heat alone. The ferrous iron contained in the greenish chloritic minerals already noted as characteristic of the Payette sediments could thus have been oxidized to ferric iron oxide and the red color thereby produced. Although it seems most likely that these lavas were erupted into water, this oxidation could probably have been produced if the lava were erupted on to a moist playa or on to a river flood plain beneath either of which there would be a high water table.

Some flows of the normal dark-colored Grassy Mountain basalt grade laterally into a lavender- or red-colored rock, which in many places obtains throughout the entire thickness of a flow. This color is not the result of weathering, and it is probable that the areas of red lava represent the former course of the hot vapors in their upward passage through the basalt, the vapors having been generated near the contact of the basalt and the underlying wet sediments. Action by these hot gases (pneumatolytic of a certain type) or a combination of it and hydrothermal action have caused the olivine to be completely altered to iddingsite, the outline of the olivine crystals still being preserved, and in some instances the iddingsite has again been completely altered to a reddish unidentified material consisting mostly of hematite. The original augite has also been partially altered, and the groundmass of the rock has been stained red. Alteration of the olivine and augite in this manner was observed only in

[1] J. T. Pardee and Kirk Bryan, "Geology of the Latah Formation," *U.S. Geol. Surv. Prof. Paper 140* (1924), p. 12 and Pl. IV, *C;* H. T. Stearns, "Geology and Water Resources of the Kau District, Hawaii," *U.S. Geol. Surv. Water-Supply Paper.* (In preparation.)

the red phase of the Grassy Mountain basalt. This agrees with the conclusion recently arrived at by Ross and Shannon[1] that iddingsite is not a mineral that results from ordinary weathering processes.

In the vicinity of Deer Butte there are three distinct flows of Grassy Mountain basalt, each separated by beds of fine-grained ashy sediments (see intervals 6–10, sec. 3). At the base of each successive flow the ash is baked red for 2 feet or more, but except for this difference in color, the character of the material above and below the basalt is the same and there is no evidence of any unconformity or stratigraphic hiatus of any sort. Thus deposition in the vicinity of Deer Butte was not interrupted during the extrusion of the basalt and the same type of material was deposited throughout. As previously set forth, these fine-textured materials are thinly laminated (intervals 6, 8, and 10, sec. 3), and although it is recognized that successive showers of ashes on land would also produce a stratification, it seems that, in default of other evidence, within this interval of several hundred feet of beds indicating subaerial condition such as conglomerate, carbonaceous material, or silicified wood, continuous subaqueous deposition in this vicinity took place. During this time three successive flows of Grassy Mountain basalt were erupted, two of which are shown in section 3. These three flows were presumably erupted into the body of water in which the volcanic ash was being laid down.

Butler and Burbank[2] point out that in the Lake Superior region many of the basalt flows consist of a lower massive, dark-colored portion known as trap and an upper vesicular part which is red in color and thus resembles some of the basalts in this region. Analyses of certain individual flows with red tops both in the Lake Superior region and elsewhere are cited by them, and the important point is brought out that though the total iron content of the rock in many instances is approximately constant throughout the flow, there is a very definite increase in the ratio of ferric to ferrous iron from the bottom to top of the flow. They conclude that both the oxidation

[1] C. S. Ross and E. V. Shannon, "The Origin, Occurrence, Composition, and Physical Properties of the Mineral Iddingsite," *U.S. Nat. Museum Proc.*, Vol. LXVII (1925), Art. 7, pp. 1–19.

[2] B. S. Butler and W. S. Burbank, "The Copper Deposits of Michigan," *U.S. Geol. Surv. Prof. Paper 144* (1929), pp. 34–45.

and concentration of iron was accomplished by gases probably CO_2 and H_2O) escaping from the solidifying and crystallizing lava, the enclosed gases being either neutral or reducing toward iron at the temperature at which the lava emerged, but they became strongly oxidizing as the temperature decreased, with the result that much ferrous iron was converted to the ferric state, the conversion being more and more complete as the upper part of the flow was approached.

A reaction similar to the foregoing very probably took place within the basaltic magmas of this region at the time of eruption and, in the presence of water, it might reasonably be expected that this oxidation of ferrous to ferric iron would be even more vigorous.

Turning to a consideration of the petrologic evidence that bears on this question of water deposition of same of the basalts, it is believed that the chlorite and carbonate in these vesicles (Fig. 10, *C* and *D*) at the top of the flow of interval 9, section 3, which have been previously described are in all probability due to hydrothermal action. A peculiar amygdaloidal andesite of similar texture and mineralogical association described by Ross and Shannon[1] is apparently interbedded with lake sediments, and Ross[2] believes that this texture is likely due to hydrothermal action and considers it probable that this andesite also was poured out under water.

It was noted that the zeolite heulandite is abundant in the Grassy Mountain basalt, but zeolites are not necessarily distinctive of subaqueous basaltic flows. However, of several descriptions of North American basic igneous rocks which have been affected by hot solutions all contain an abundance of zeolites whether these solutions were of magmatic (juvenile) or meteoric origin or resulted from the heated water in which the lava was submerged.

Lindgren,[3] in discussing zeolites in general, says:

> The accepted authorities are more or less vague in their statements as to the formation of zeolites, especially in amygdaloidal rock. . . . . Zeolites are manifestly unstable in the zone of weathering and must have been formed at some depth. Of late years, the opinion has been gaining ground that zeolitization, in

[1] C. S. Ross and E. V. Shannon, "Nordenite and Associated Minerals from near Challis, Custer County, Idaho," *Proc. U.S. Nat. Museum*, Vol. LXIV (1924).

[2] Ross, personal communication.

[3] W. Lindgren, *Mineral Deposits* (New York, 1919), p. 429.

basic volcanic rocks, is distinctly connected with the cooling process and in fact should be regarded as an after-effect of volcanism, their deposition taking place in the still hot rocks. . . . . That zeolitization is far from being simply an effect of the leaching by surface waters is shown by the absence of the zeolites from large areas of basic flows, many of them full of vacuoles or blowholes. Few occurrences have been recorded from the Hawaiian flows, which are apparently well suited for their deposition, or from the extensive flows of the Columbia lava in Oregon and Washington. There are, therefore, certain conditions—not yet fully elucidated—which are necessary for the deposition of zeolites. *It is probable that their development would be greatly furthered if the eruption of the effusive rock took place under water;* the sea water would cool the surface of the flow and a slow downward movement would be caused in the porous rock. Besides, these conditions would give rise to a system, cool at one end, hot at the other, in which circulation competent to effect concentration would be initiated.

From the foregoing citations it appears that several authorities believe that many, though not all, lavas containing zeolites have been erupted under water. The presence of zeolites in the Grassy Mountain basalt may thus be taken as corroborating evidence that some of this basalt was wholly or partly submerged while it solidified, and makes it more probable that the red color in certain sedimentary beds beneath the lavas, and in certain parts of the lava flows themselves, is due to the influence of surface water heated by the lavas. The peculiar characteristics of the Grassy Mountain basalt and of the underlying baked beds in general appear consistent with the supposition that this lava flowed out into a very shallow body of water.

Blackjack basalt.—West-northwest of Blackjack Butte in the vicinity of the two small "cinder cones" the fine-grained silts of the Payette formation have been baked red immediately below the Blackjack basalt.

On the same criteria used above for the Grassy Mountain basalt, it is possible that this flow of the Blackjack basalt was also extruded in water. The question then arises as to the origin of the two "cinder cones." These masses of brick-red cinders form a distinctive unit and rest directly on dense black basalt correlated with the Blackjack flows. Since these red cinder cones have the quaquaversal dips and other characters of volcanic cones, they are believed by the author to represent true centers of volcanic eruption. However, in Hawaii,

Stearns[1] reports that red scoriaceous masses very much like ordinary cinder cones are formed by secondary eruptions of the liquid basalt on the top of the flows where they enter the sea. It is therefore possible that these red scoriaceous masses may have been formed by lava that was originally erupted into water.

Owyhee basalt.—The Owyhee basalt in interval 2 of section 1 contains several thin beds of stratified tuff apparently deposited in water. Wherever observed the top of these beds are reddened and baked for about 2 feet by the overlying basalt flow.

As previously mentioned, several sills near the north end of Hole-in-the-Ground are intruded into the older Tertiary (pre-Owyhee) sedimentary rocks and have metamorphosed these sediments for a distance of from 3 to 6 feet above the sills. The sills have changed the color from the normal tan and buff green to a mottled mixture of dark brick red and dark brown green. This partial oxidation may have been furthered by water already in the sediments or by water contributed from the basalt. The red color in these sediments is not as brilliant as that which characterizes the altered sedimentary beds immediately below the Grassy Mountain basalt.

About 2 miles north of the Box a number of thin red lava flows were examined rather closely, and here the basalt, which is glassy, contains vugs, veinlets, and amygdules of calcite and zeolites. The nature of the basalt in this locality suggests that the basalt was erupted into water and there quickly chilled (Fig. 6, *C*). Perhaps the body of water was deeper and more extensive than those which existed at the time of eruption of some of the flows of Grassy Mountain basalt.

Ellipsoidal structure.—Russell[2] has described a flow between Bliss, Idaho, and the mouth of the Salmon River in the basalt of the Snake River plain, and Pardee and Bryan[3] have recently, with the help of Sampson, described lavas near Spokane, which are supposed to have solidified under water. In both of these localities pillow structure is

[1] Stearns, *op. cit.*

[2] I. C. Russell, "Geology and Water Resources of the Snake River Plain," *U.S. Geol. Surv. Bull. 199* (1902), pp. 113–17.

[3] J. T. Pardee and Kirk Bryan, "Geology of the Latah Formation in Relation to the Lavas of the Columbia Plateau near Spokane, Washington," *U.S. Geol. Surv. Prof. Pap. 140A* (1926), pp. 13–15.

present and is regarded as evidence of subaqueous origin, though no supporting evidence of such origin is presented. No pillow structure was observed in that part of Malheur County described in this paper; its absence, however, can hardly be regarded as evidence that none of the lavas here was water cooled. The diagnostic value of pillow structure seems rather doubtful.

Although the ellipsoidal or pillow structure in many basalt flows is doubtless the result of lava having been poured into water, it has been pointed out by Lewis[1] that many flows which possess this structure are of subaerial origin. He points out that the absence of pillow structure, on the other hand, does not preclude the possibility of subaqueous cooling, for many of the recent basaltic flows in the Hawaiian Islands that have flowed in the sea have not developed any peculiar or distinctive structure.

STRUCTURE

The geologic structure of this area simulates a northward plunging anticline which has been faulted along the flanks. Most of the major faults are roughly parallel to the general trend of the anticline, but there are several important faults which are almost normal to the axis (Fig. 1). Apparently this anticline is on the northward-dipping monoclinal slope, which is the south side of the Snake River basin. The structural data which define this Owyhee River anticlinal nose may be briefly set forth: West of the Owyhee River the Owyhee basalt dips from 5° to 12° west. In the latitude of Blackjack Butte the average elevation of the easternmost outcrop of the Owyhee basalt is about 3,000 feet, and within a distance of 5 miles to the east, the elevation of the land decreases to 2,250 feet at the edge of the plain bordering the Snake River, in which place the Owyhee basalt is below the surface, which means that the Owyhee basalt dips eastward at least 2°. The Owyhee basalt in the northern part of this area stands at an elevation of 3,000 feet in many places, and 25 miles north-northeast of this area, at Ontario (elevation 2,159 ft.), a well 3,650 feet deep which extended to 1,489 feet below sea-level was in the Payette formation throughout its entire depth and no basalt was

[1] J. V. Lewis, "Origin of Pillow Lavas," *Geol. S. Amer. Bull.*, Vol. XXV (1914), pp. 591–654.

encountered.[1] It is evident, then, that the surface of the basalt also slopes northward at an angle of at least 2°, thus denoting the presence of an anticlinal nose. Our mapping was not carried sufficiently far southward to determine if the rocks dip to the south, and it is therefore unknown whether or not the structure closes in that direction.

Although the structure reflected by the Owyhee basalt resembles an anticline and probably was formed as a result of pre-Payette folding, it might have resulted because the center of eruption of the basalt was near the axis of this structure, from which center the molten rock flowed east, north, and west. It is also conceivable that if the basalt flowed out on to a hill surface that sloped east, north, and west, this anticlinal type of a structure might have been developed.

The hypothetical diagram (Fig. 2, *A*, *B*, and *C*) across the central part of the area shows the probable structural relations that are believed to have existed before and after faulting and subsequent erosion. The map (Fig. 1) and the geologic cross-sections (Fig. 3) show that after the extrusion of the Grassy Mountain olivine basalt this structure, which simulates an anticline, was deformed by normal faults, and that, though the most persistent faults and those possessing the greatest displacement generally trend approximately north-south, there are faults oriented at angles varying up to 90° from north-south. Some of the more important of these faults are briefly referred to below.

In the northeastern part of the area mapped there is a north-south fault, which possesses the largest maximum displacement of any fault found in the region. Here the top of the Owyhee basalt has been dropped to the east against the upper beds of the underlying older Tertiary sediments, thus involving a displacement of not less than 1,300 feet. The slip of this fault decreases rapidly southward. West of Blackjack Butte, in the vicinity of the small cinder cones, there is a rather complexly faulted area where the Payette sediments have been dropped down considerably below the top of the Owyhee basalt.

The precipitous face of Blackjack Butte is caused by a normal

[1] C. W. Washburne, "Gas and Oil Prospects near Vale, Oregon, and Payette, Idaho," *U.S. Geol. Surv. Bull. 431* (1911), p. 40.

fault with a downthrow to the west trending north-northeastward. The maximum slip along this fault plane apparently exceeds 400 feet. Approximately 1 mile northwest of this fault there is another fault with similar trend, which also has the downthrow on the west, but with less displacement.

The Grassy Mountain basalt is clearly involved in this faulting and the deformation which, therefore, probably took place at least as late as the Miocene or early Pliocene. There are no field data within the area mapped to show how recent the deformation may have been, but it is apparent that the Idaho beds in Deer Butte and Mitchell Butte (north of the map, Fig. 1) have been uplifted and deformed, and that the later stages, at least, of the faulting may have taken place in late Pliocene or early Pleistocene time.

"SEINE" OR "COUTCHICHING"?

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ABSTRACT

In the vicinity of Sapawe and Steep Rock lakes, Rainy River district, Ontario, is a large series of schistose pre-Cambrian sediments bordered on the north by basic volcanics (Keewatin), and on the south by intrusive granite. They strike west to Rainy Lake and to the east gradually finger out into the granite. Geologists have assigned the sediments a stratigraphic position both below the Keewatin, as "Coutchiching," and above the Keewatin, as "Seine." This paper deals with the structure of the sediments along the Keewatin contact in the area first mentioned. Evidence, based on minor structures in the sediments and the major structures of the area, is presented to show that the contact has suffered faulting of the shear type, and that the apparent dip of the sediments under the Keewatin is not definite proof of their age. The larger structures, involving faults and discordant folding of the disputed sediments and the Steep Rock Lake sediments near by, are interpreted as due to one period of diastrophism related to the intrusion of "Algoman" granites. The data given favor a Seine age for the sediments, but since areal mapping is incomplete, the question is left open.

INTRODUCTION

Northwest of Lake Superior in Rainy River district, Ontario, is a large series of schistose sedimentary rocks which strike easterly from the classic Rainy Lake area, and, paralleling the Canadian National Railway, extend to the equally famous Steep Rock Lake and beyond to Sapawe and Crooked Pine lakes, a distance of about 90 miles. Geologists have assigned these rocks two general ages in the pre-Cambrian: "Coutchiching" or pre-Keewatin and "Seine" or post-Keewatin. As the latter they have been correlated with early and late Huronian rocks of the American side. The problem of age of the sediments is important in connection with the early pre-Cambrian history of North America, and the correlation of Canadian and American successions. Sediments of at least two ages are present in the areas mentioned. Post-Keewatin sediments of small distribution occur at East Shoal Lake and at Steep Rock Lake. There is little agreement as to the correlation of these, or as to the age of the much larger series which lies to the south, here called the "Southern Sedimentary" series.

Detailed mapping of the area has been carried on by the Canadian Geological Survey. In the summer of 1928 the writer had the op-

portunity of studying the problems while making a survey of the mineral resources of the region for the Ontario Department of Mines. A detailed map was made of the Sapawe Lake area, lying just east of Steep Rock Lake. To the west, near Atikokan, Jackfish Lake, and East Shoal Lake, the sediments were examined more briefly. The problems are much too complicated to warrant final conclusions after such a short study, but since the area will probably be examined again by others, the results and tentative conclusions

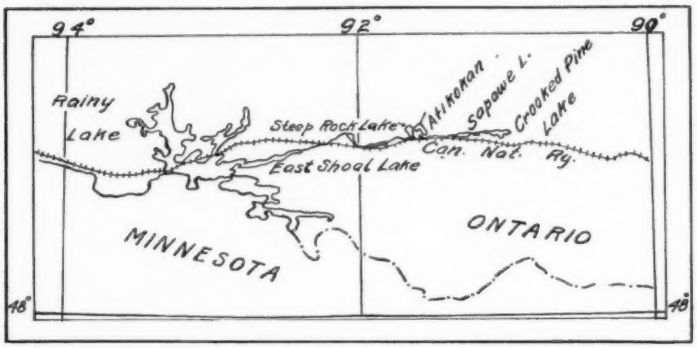

FIG. 1.—Index map showing areas referred to in this paper

made are presented here in the hope that they may contribute something to an ultimate solution.

Those who have studied the area include W. H. Smith and W. McInnes, Lawson, Walcott, Uglow, Van Hise and Leith, Grout, Bruce, and Tanton.

GENERAL GEOLOGY

A generalized table of formations in the Sapawe and Steep Rock lakes area is given below with the various age possibilities indicated.

Near Steep Rock and Sapawe lakes (Fig. 2) the sediments strike in a fairly uniform easterly direction and are intruded on the south by red biotite granite and gneiss. On the north they are bounded by Keewatin volcanic flows, now altered largely to greenstones. At Steep Rock Lake the Steep Rock Lake series of conglomerates, limestones, basic lavas, and obscure green schists strikes in a northwest-

erly direction and occurs as a close synclinal fold overlying the contact of Keewatin lavas and Laurentian granite. To the east of Steep

TABLE OF FORMATIONS

	Sapawe Lake Area	Steep Rock Lake Area	Remarks
Recent and Pleistocene	River silts, glacial drift, morainic and fluvo-glacial deposits of sand gravel, and boulder clay		
Pre-Cambrian Algoman	Red biotite granite and gneiss		
	Intrusive Contact		
Seine	Sedimentary series, south of Atikokan River system, quartzites, arkosites, slates		Coutchiching of McInnes and Tanton; both Seine and Coutchiching of Lawson; position with respect to Steep Rock Lake series questionable
Post-Steep Rock Lake	Diabase, diorite, and gabbro	Gabbro	Possibly Algoman or even Keweenawan
	Intrusive Contact		
Lower Huronian (?)	.....	Steep Rock Lake series, limestone conglomerate, and volcanics	
	Unconformity		
Laurentian	Gray hornblendic to biotite granite and granite gneiss, quartz porphyry, and related rocks		
	Intrusive Contact		
Keewatin	Chlorite and hornblende schists, metabasalts, and other volcanics		
Coutchiching	Sedimentary series		Listed above as Seine

Rock Lake the Southern Sedimentary group is separated from the Laurentian granite gneiss on the north by a narrow band of Keewa-

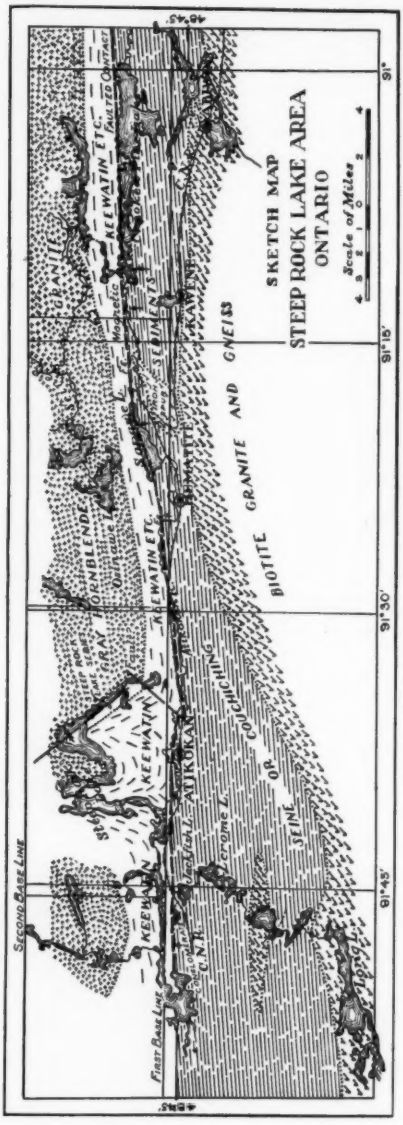

FIG. 2.—Sketch map of Steep Rock Lake area, Ontario

tin greenstones. These are much intruded by old altered gabbros and diorites, by quartz porphyries, and by a few younger diabase dikes. Along the contact of this essentially basic group of rocks and the sediments lie the magnetite-pyrrhotite deposits of the Atikokan iron range which occur generally in much-altered gabbros as replacement bodies. Just to the south of the Atikokan iron mine an elliptical stock of red biotite granite intrudes the sediments. West of Steep Rock Lake, near Jackfish Lake, a small conglomerate lens occurs along the contact of Keewatin and sediments. This conglomerate is clearly post-Keewatin as it contains pebbles of basic volcanics, quartz, granite, and porphyry. All who have examined the occurrence are agreed as to its post-Keewatin age.

In this area McInnes[1]

[1] W. McInnes, *Pt. H. Ann. Rept., Geol. Surv. of Can.*, Vol. X (1899), pp. 17, 25–26.

first classed the southern sediments as Coutchiching, but on his map they were not completely differentiated from the Keewatin. Later Lawson[1] considered the northern part of the series as post-Keewatin (Seine), the structure being interpreted as monoclinal, dipping steeply south and resting unconformably on the Keewatin. The conglomerate and iron deposits were considered as complementary features at the base of the Seine. South of Jackfish Lake, at the south end of Lerome Lake, Lawson[2] divided the series on a basis of metamorphism, calling the southern portion Coutchiching, and correlating it with the Coutchiching of Rainy Lake. The Seine series here was considered as younger than even the Steep Rock Lake series, chiefly because the folding of the latter was discordant with and not recognized in the Southern Sedimentary series. Grout[3] on examining the area agreed with Lawson as to the post-Keewatin (Seine) age of the northern part of the series, but could find no evidence for dividing it into Seine and Coutchiching. The structure was then shown to be a series of steep and broad folds rather than a monocline. Tanton,[4] on the other hand, while admitting that the sedimentary rocks were of one age in the Jackfish-Lerome Lake section, placed them all as pre-Keewatin (Coutchiching), since he found the series dipping under the Keewatin on the north. The conglomerate lens near Jackfish Lake was correlated with the conglomerate at the base of the Steep Rock Lake series.

At East Shoal Lake (Rainy Lake district) Lawson mapped the Seine series of conglomerates, quartzites, and slates, which rest unconformably above both Keewatin and Laurentian and are closely folded into synclines striking east. This series he considered the same as the sedimentary rocks occurring along the strike in the Steep Rock–Sapawe Lake area. To the south of East Shoal and Rainy lakes lies the wide area of mica schists called Coutchiching, which

[1] A. C. Lawson, "Geology of Rainy Lake Re-studied," *Geol. Surv. of Can. Mem. 40* (1913), pp. 59, 65–66.

[2] *Ibid.*, p. 78.

[3] F. F. Grout, "Coutchiching Problem," *Bull. G.S.A.*, Vol. XXXVI (1925), p. 359.

[4] T. L. Tanton, "Recognition of the Coutchiching near Steep Rock Lake," *Trans. Royal Soc. Can.*, Vol. XX, sec. IV (1926), pp. 39–49; "Stratigraphy of the Northern Sub-province of the Lake Superior Region," *Bull. G.S.A.*, Vol. XXXVIII (1927), pp. 731–48; *Sum. Rept., Pt. C. Geol. Surv. of Can.* (1925), p. 5.

also strike easterly and are separated from the Seine series by a narrow band of Keewatin green schists of igneous origin. This band narrows westward until the Seine conglomerates are contiguous with the Coutchiching mica schists. Grout here questioned Lawson's structure and believed that the so-called Coutchiching dips south, overlying rather than underlying the Keewatin.

The principal work of the writer was confined to the northern contact of this great sedimentary series in the area extending from Atikokan to Crooked Pine Lake (Fig. 2). The conglomerate lens at Jackfish Lake was also examined. Details of the lithology and structure are given below, followed by a discussion of the possible interpretations and conclusions.

LITHOLOGY OF THE SOUTHERN SEDIMENTARY SERIES

The lithology of the Southern Sedimentary series has been thoroughly described by Lawson[1] and Tanton.[2] In general the beds are thin, 1–3 inches thick, and consist of interlaminated slates and quartzites or arkosites. All are fine grained and schistose. East of Atikokan no conglomerates are present. Near Crooked Pine Lake massive arkosic beds predominate, and were it not for a few slaty layers their distinction as sediments would be difficult.

The arkosites contain quartz and altered feldspar, ranging in composition from orthoclase to oligoclase, in a fine chloritic groundmass. The slates are usually in very thin beds, and with more quartzose layers give the sediments a distinct varved appearance. All the slates show intense shearing.

Near Iron Spur, as described by Lawson,[3] the sediments have been intruded by granite and altered near the contact to dark-quartz biotite and quartz-hornblende schists.

The arkosic nature of the sediments shows they have been derived from a landmass of granitic composition largely by mechanical disintegration.[4] The fine grain and evenness of the strata point to their deposition in quiet waters at some distance from the old shore line.

[1] *Op. cit.*, pp. 75–78.

[2] "Recognition of the Coutchiching near Steep Rock Area," *op. cit.*, pp. 44–45.

[3] *Op. cit.*, p. 78. [4] *Ibid.*, p. 62.

It has been suggested by Bruce[1] that similar sediments to the west are of deltaic origin. The absence of interbedded conglomerates, or of a well-established basal conglomerate, is exceptional in view of their probable origin, and as will be seen later, in the light of their isoclinally folded structure. If they are pre-Keewatin, conglomerates may of course underlie the strata now exposed; if post-Keewatin, the few conglomerates exposed along the north contact are probably a part of the main series. Details regarding the Jackfish Lake occurrence are given later.

STRUCTURE OF THE SOUTHERN SEDIMENTARY SERIES

Determination of the true structure of the Southern Sedimentary series, and its origin if possible, is vital in arriving at any conclusions as to the age of the rocks. The acquisition of more data in the past has shown the structure to be more complex than was formerly supposed. Facts found by the writer do likewise, but a rather simple solution is given to explain many apparent anomalies. All the strata are on edge or dip steeply north or south. The majority of beds appear now to dip steeply south. They have a remarkably uniform strike of N. 65–85° E. All are somewhat schistose, and since there are no marker horizons, any conception of the major structures must be gained by careful study of tops and bottoms of beds, fracture and flow cleavage, and drag folding. Study of these was confined largely to the northern part of the series.

MINOR STRUCTURAL FEATURES AND INTERPRETATION

Determination of the tops of beds and from them the structure was attempted by means of gradations in size of grain, particularly in the thinly bedded arkosites. Many instances were noted in which an apparent coarse grain was produced on both sides of one bed by the injection of narrow quartz stringers. At no place in this area was cross-bedding observed. Of innumerable detailed examinations of the sediments made near the Keewatin contact only five cases were found where a gradation in grain showed indisputably that the tops were on the north. (These are indicated by arrows on Fig. 2.) One

[1] E. L. Bruce, *Ontario Dept. Mines, Ann. Rept.*, Vol. XXXIV, Part VI (1925); "The Coutchiching Delta," *Bull. G.S.A.*, Vol XXXVIII (1927), pp. 779.

case was noted where the opposite was true, and the significance of even this one should not be overlooked. However, since the first five examples are rather uniformly spaced along the northern border, it may be concluded that here the sediments appear to dip under the Keewatin, as noted by Tanton,[1] for the region lying to the west of Steep Rock Lake. As will be seen later, it is possible that locally the sediments may dip over rather than under the Keewatin.

Determination of the attitude of the beds was also attempted by means of the relation of fracture and flow cleavage to the bedding in both horizontal and vertical sections. This determination depends on the manner in which the regional cleavage was formed, whether by folding and differential movements between beds, or by faulting or shearing movements following the folding. The determinations in this area are of less certain value than changes in size of grains. Not only are they difficult to make with accuracy, since the cleavage and bedding on the whole differ in dip by only a few degrees, but the dips in many places vary from steeply north to steeply south. This may be due to minor crumpling or later tilting. Three prominent cleavages (Figs. 3, 4) are displayed in the beds. One (No. 1), a slaty cleavage in the thin, fine-grained beds, cuts the bedding at a very low angle and has generally a more northerly strike. Another, the most prominent and regular cleavage (No. 2), strikes at an angle of 10°–30° more northerly than the beds, often cutting across beds of different composition. A third set of cleavages is found locally, south of Atikokan station, superimposed on the second, and striking more southerly than the beds. It is evident, then, that there have been shearing movements other than those related directly to the folding, though not necessarily separated from the folding much in time. The cleavage best related to the folding is the one in the slaty beds. The

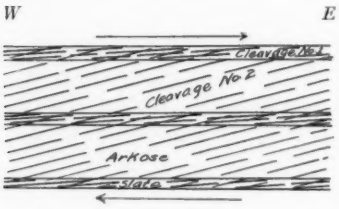

FIG. 3.—Diagram showing two cleavages in sediments. Cleavage 2 is far the more dominant, occurring in both arkosic and slaty beds, and in the latter often obscuring cleavage 1.

[1] "Recognition of the Coutchiching near Steep Rock Lake," *op. cit.*, p. 46.

second cleavage mentioned may be due also, in part, to this cause. In either case, both strike more northerly than the beds, the latter at a greater angle than the former. Determinations of top of beds by these cleavages along the northern border of the sediments again give the majority of tops on the north, but several exceptions to this were noted with the top on the south. With regard to the folding, however, the cleavages are more significant. The attitude of the slaty cleavage (No. 1) and of the more dominant cleavage (No. 2) indicates that the strata are almost isoclinally folded with nearly vertical axial planes striking at a relatively small angle (5°–20°) more to the north than the usual strike of the beds near the Keewatin contact. These axes are truncated by the northern Keewatin contact, and with close folding and with the axes spaced within $\frac{1}{4}$–$\frac{1}{2}$ mile[1] of each other, it is apparent that locally the beds on the north will appear to dip under and elsewhere over the Keewatin. Thus apparent differences in the attitude of the beds along the Keewatin contact may be explained.

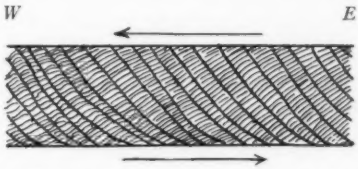

FIG. 4.—Diagram showing two ages of cleavage produced by opposite differential movements. The one striking northwest is the later and has caused a slight displacement of the other striking northeast.

The attitude of drag folds in the sediments may also be used. Minor drag folds were found pitching both to the east and to the west in about equal numbers. This, like the opposite cleavages, may indicate opposite movements, but it might also be explained in still another way. W. J. Mead[2] has shown that folds, besides being produced by simple compressive stresses, may be formed by horizontal shear. Folds resulting from this type of stress are arranged *en échelon* and pitch in both directions along their axes.

The minor structures, then, indicate that along the northern border of the sediments the beds usually appear to dip under the Keewatin, but locally the reverse seems true: that the series is folded

[1] *Ibid.*

[2] "Notes on the Mechanics of Geologic Structures," *Jour. Geol.*, Vol. XXVIII (1920) p. 519.

with axes striking into the Keewatin contact at a low angle and that the folds may pitch in both directions along the axial planes. More than one movement is indicated. Movements slightly later than the folding may be related to a period of major faulting as is shown below.

EVIDENCE OF FAULTING ALONG THE SEDIMENT-KEEWATIN CONTACT

A major structural feature not hitherto mentioned is a fault along the contact of the Southern Sedimentary series and the Keewatin. Everywhere this contact is characterized by 100–300 feet of highly schisted rocks, identifiable as sediments or volcanics only by their general composition. The greater part of the contact is marked by a topographic depression, occupied by the Atikokan and Lower Seine River systems. From Sapawe Lake to Magnetic Lake the strike of the beds parallels the contact with the greenstone complex on the north. Through Sapawe Lake the contact swings northward, perhaps due to the elliptical intrusion of granite at Iron Spur. From Magnetic Lake to the east end of Crooked Pine Lake, however, careful plotting and projection of strikes brings out the fact that the strata are truncated at low angles of 5°–20° by the contact, which is here almost a straight line. Similar truncation of inferred axial planes has been noted; the truncation of the beds close to the contact cannot be explained by folding; but both conditions suggest a fault of considerable magnitude, though it is admitted no actual example of truncation was found due to the buried nature of the contact. It is believed that this structural feature continues westward approximately parallel to the strata.

Further proof of the faulted nature of the contact is found in a study of the major folds of the region. Earlier investigators[1] tentatively placed the Southern Sedimentary series as younger than the Keewatin and Steep Rock Lake sediments. Evidence for this conclusion consisted of the supposed monoclinal structure of the southern sediments, and the discordance of the folding in the two groups of sediments (Fig. 2). The folds in the Steep Rock Lake sediments strike northwest-southeast and are nowhere reflected in the easterly

[1] A. C. Lawson, *op. cit.*, pp. 81 and 104; *Geol. Surv. Can. Mem. 28* (1912), pp. 9–10.

trending southern series.[1] Hence the southern sediments were assumed younger than the folding of the Steep Rock Lake series and adjacent Keewatin. More recent observations by both Tanton[2] and the writer indicate, however, that for the most part the southern sediments now dip under the Keewatin on the north. If these sediments are actually younger than the Keewatin and Steep Rock Lake series, a fault of some size is obviously required to account for their present position beneath older rocks.

On the other hand if the southern sediments are of pre-Keewatin (Coutchiching) age, as suggested by their dip, one must explain why the northerly folding of both Keewatin and Steep Rock Lake sediments is not reflected as cross-folds in the still older rocks to the south. There can be no doubt as to the essential correctness of the discordant trends of folds as shown on existing maps of the Canadian Geological Survey. The only possible explanation is that the contact of sediments and Keewatin is faulted, and that the northerly trending folds were thereby localized on the north.

Thus, no matter which is the age of the sediments, a fault of considerable size is required to explain the structure. That no fault gouge or breccia was observed along the fault zone may be explained by lack of exposures and by obliteration of such evidence by long-continued shearing.

Some indirect evidence of faulting may be given also. In the Sapawe Lake area the magnetite and pyrrhotite deposits of the Atikokan iron range occur just north of the Keewatin sediment contact in altered basic intrusives. They have a distinct linear arrangement and parallel the contact for many miles, indicating a definite structural control over their deposition. They are replacement deposits, and since they do not occur exactly in the contact, but within adjacent igneous rocks, fracturing and shearing of these rocks must have influenced their deposition rather than the existing plane of weakness along the contact. The fracturing and shearing can best be related to a major fault along this zone.

[1] C. D. Walcott, "Steep Rock Lake Fossils," *Geol. Surv. Branch, Dept. Mines, Can. Mem. 11* (1911).

[2] "Recognition of the Coutchiching near Steep Rock Lake," *op. cit.*, p. 46.

Again, west of Steep Rock Lake, Tanton[1] has described the Keewatin rocks as more schistose and variable in composition along their southern contact with the sediments than farther north. This was recognized as being due to possible faulting, though the variation in composition of lavas adjoining the sediments might be accounted for by the manner in which they were laid down.

NATURE AND DIRECTION OF FAULT MOVEMENT

Some inferences may be drawn as to the nature and direction of the major fault movement from both major and minor structures in the sediments. In using minor structural features such as drag folds and cleavages inferences are less certain, since some of the cleavages are undoubtedly due to the original folding, though if folding and faulting are due to the same direction of stress, the cleavages in each case would be somewhat similar.

The dip of the fault plane is indicated approximately by the dip of the schistosity along the fault zone. This, in general, is vertical, with variations of 10° to the north or south. The highly schistose nature of the fault zone suggests that it is more of a shear than a normal fault type.

Of the horizontal movements indicated along the fault by minor structural features, that of the north side east seems the more prominent. Evidence of this is based on the more northerly trend of the most prominent cleavage as compared with the bedding. Though this cleavage may be due in part to the original folding, it may also be the result of a continued stress which later produced the faulting. In either case it implies a differential movement of the north side eastward and the south side westward. Similar evidence is found along the contact $1\frac{1}{2}$ miles east of Atikokan where a fault of post-Steep Rock Lake series age has been mapped.[2] This fault swings southwest from the east arm of Steep Rock Lake and cuts across the faulted contact of the Keewatin into the sediments where it is indicated by a schistose and much crumpled zone, and on the east side, by the offsetting of the Keewatin-sediment contact to the south (Fig. 2). The nature of the offset as shown on the map points directly to movement of the north side eastward. As will be shown later, it is

[1] *Ibid.* [2] Map C-3, *Can. Geol. Surv. Guide Book 8*, Part I (1913).

probable that this fault is closely related in age with the main one under discussion.

Farther west, near the conglomerate lens in the vicinity of Jackfish Lake, the Keewatin-sediment contact appears in the shape of a drag fold, which again may only be accounted for by an easterly movement of the north side. Faulting of this contact probably preceded the drag folding which is also reflected in the conglomerate itself (see Fig. 9).

Few positive data regarding the vertical displacement along the faulted contact are at hand, but east of the Steep Rock Lake fault are suggestions that the south sedimentary side has moved up an appreciable amount, and west with respect to the north Keewatin side. To account for the abrupt termination of the Steep Rock Lake series southeast of this fault, a movement of the kind postulated is required, the southern extension of the Steep Rock Lake sediments having been uplifted and removed by erosion. Also at Mile 139 on the railway, which there parallels the contact, gouges and a crude mullion structure occur along the face of schistose sediments which strike approximately N. 70° E. and dip vertically. The slickensiding and gouges indicate a movement of the south side up and west past the north at an angle in the east-west vertical plane of 30°.

The easterly trending contact between the Keewatin and Southern Sedimentary series appears to be faulted in the Sapawe–Steep Rock Lake area. The fault zone now exposed is essentially vertical. Movements of opposite directions are indicated along this zone. The major movement, suggested by the data at hand, is that the south side moved west and up with respect to the Keewatin on the north. Of the two components, the horizontal one, parallel to the fault, seems the greater since the fault is nearly vertical and gouges dip at 30° east in the fault plane. This and the intense schisting along the fault indicate clearly that the fault is not of a simple gravity type but mainly of a horizontal shear origin. That the shearing may have been accompanied by some thrusting of the south block over the north is suggested by the slight overturning of the folds toward the south; but the magnitude of the thrusting is not known. Indications of an opposite direction of shearing (north side west) are of a minor order and are to be expected.

INTERPRETATION OF AGE AND RELATION OF FAULT TO OTHER STRUCTURES

The age of the faulting is important. In time it is preceded by the folding of the sediments on the south, but by what interval is questionable. The fact that the north-south folding of the Steep Rock Lake series and Keewatin near by on the north of the fault does not appear on the south side may be taken as an indication that the faulting is younger than the folding of the Steep Rock Lake series. The occurrence of the Atikokan magnetite and pyrrhotite deposits[1] along and near the fault zone, and their possible relation to nearby intrusive granites, suggests also that the fault preceded slightly the intrusion of granite and the infiltration of the ores.

While it is often dangerous to infer directions of stress from a given structure, it is profitable to consider here the stress-strain relationships of both the fault and the folded rocks in the vicinity, and thereby inquire as to the relation between the folding and faulting. If all the structural features fit a given stress or stress couple, some deductions then may be considered.

All the known details of the fault have been given. It is suggested that it was produced chiefly by an east-west shear, with the north side moving east. Only a few facts and inferences have been given regarding the folding. Tanton[2] has shown that the sediments lie in close folds with axes possibly half a mile apart. They are on the whole slightly overturned to the south. The axes as inferred from slaty cleavage strike slightly more to the north than the beds. Both east and west pitches of major folds are suggested by similar drag folds. Along the northern contact the beds for the most part have their tops on the north, but locally the opposite is true, and other geologists have come to opposite conclusions there as to the structure. Thus we have a suggestion of the orientation of the folds. As noted in the foregoing, Mead[3] has shown that folds produced by horizontal shearing movements are arranged *en échelon* with their axes parallel to the direction of elongation and at an angle to the shearing stress (Fig. 5). The folds are elongated domes pitching in oppo-

[1] J. E. Hawley, *Ann. Rept., Ontario Dept. Mines* (1928). (In course of publication.)

[2] "Recognition of Coutchiching near Steep Rock Lake," *op. cit.*, p. 46.

[3] *Op. cit.*

site directions. With continued shearing and continued rotation of the strain ellipsoid, the direction of elongation and of the axial planes approaches parallelism with the direction of the stress and incidentally the general strike of the strata. The inferred attitude of the folds in this area fits the suggested stress in orientation to the stress, in the lack of any marked overturning, and in the two directions of pitch.

To the same stress couple inferred as capable of producing the close folding of the Southern Sedimentary series the faulting along

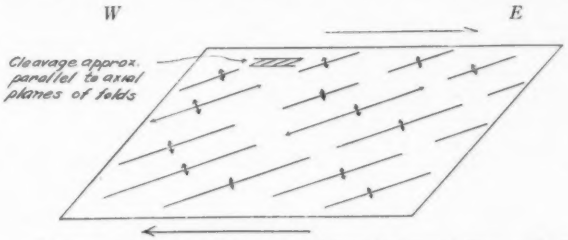

FIG. 5.—Diagram illustrating folds produced by a horizontal shear with their axes parallel to the direction of elongation and approximately parallel to the cleavage in the beds.

the northern border may be referred. The attitude of the fault is essentially vertical and nearly parallels the direction of shearing. On the strain ellipsoid it corresponds to one plane of maximum shear. The Steep Rock Lake fault, noted above, may possibly correspond to the other plane of maximum shear (Fig. 6).

It is clear, therefore, that the same stresses which produced the folds of the Southern Sedimentary series may have later produced the faults, and it is probable the two structural features are closely related in time. The relation of the structures to the Steep Rock Lake folds is still to be considered. It has been argued that the east-west folding of the southern series is younger than that of the Steep Rock Lake series which trends northerly, because the latter is not reflected in the former. Supporting this is evidence of the east-west folding continuing north of the faulted Keewatin contact for some distance, especially east of Steep Rock Lake, where the schistosity in the Keewatin parallels approximately that of the sediments. In the immediate vicinity of Steep Rock Lake, however, the east-west fold-

ing according to mapped structural trends, and a few observations by the writer, dies out rather abruptly in the Keewatin near the fault, and gives way to the northerly folds which are reflected in the shape of Steep Rock Lake.

While this suggested age relation may hold, another interpretation is offered as a tentative hypothesis, particularly for the consideration of future workers in the field. Since the determination of age of the different rock groups rests largely on the structure, all possible interpretations must be considered. The new interpretation is that all the major structures of the area, including discordant folds, were produced by the same type and same general age of stresses, rather than by stresses of different orientation exerted at vastly different times. The stresses inferred above as causing the folding of the southern series and the faulting were horizontal shearing stresses acting in an east-west direction, with the north side moving east. South of the fault, regularly easterly trending folds were formed in the homogeneous mass of sediments. These folds were later intruded by a granite batholith, which replaced rather than displaced the southern sediments, and which may be considered as an end phase of the diastrophism. North of the fault, on the other hand, must have been the Steep Rock Lake sediments, overlying the eroded contact of Keewatin lavas and Laurentian granite. This assertion depends on the conclusion reached above that the Steep Rock Lake folding cannot be younger than the folding and faulting of the southern series. It is probable that east-west shearing movements south of the fault would extend at least a few miles north of the fault. With an eastward movement of the north side on such a heterogeneous assemblage of rocks, lavas, sediments, and granite, it is clear that the re-

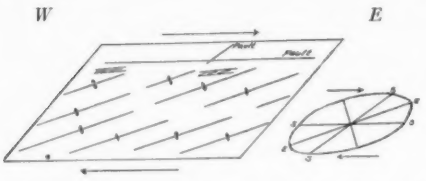

FIG. 6.—Diagram illustrating how the folds and faults in the area may be produced by the same horizontal shear, and the relation of these to the strain ellipsoid. The two faults shown are approximately parallel to planes of maximum shear (*SS*); the axes of the folds are parallel to the direction of elongation. The angle made by the axes and the east-west fault is here exaggerated.

sponse would not be the formation of folds paralleling those to the south, but of folds with an orientation dependent on the location of incompetent and competent rock masses. Figure 7 is a sketch showing the relation of such stresses to the folds of the area. It is certainly possible that the stresses inferred as producing the fault and southern folds may have produced, to the north of the fault, the discordant, northwesterly trending Steep Rock Lake folds by an easterly compression of the Keewatin and Steep Rock Lake sediments against the buttress of Laurentian granite on the east. Localization of these folds would be aided by the shear or fault zone along the contact of the Keewatin and southern sediments.

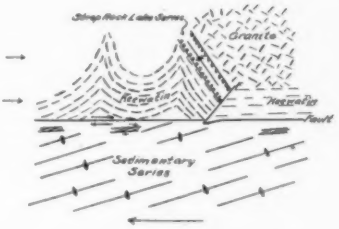

FIG. 7.—Diagram illustrating the manner in which the north-south folding of the Keewatin and Steep Rock Lake series may have been brought about by the same forces producing the easterly folding and faulting of the Southern Sedimentary series. The angle made by the axes of the folds and the contact fault is exaggerated.

Since all the major structures of the area may be related thus to one type and direction of deformation, it is also possible and even probable that they were produced at essentially the same time of mountain-building, even though locally there is apparent evidence of some difference in age. An analogy to faults and fractures of apparently different ages in an igneous intrusion all of which are due simply to cooling may be drawn. Here, the discordant folds are not alone sufficient evidence to prove great differences in their age nor in the age of the sediments.

The age of this widespread deformation is of necessity post–Steep Rock Lake series. Since granites, younger than the Laurentian and named Algoman by Lawson, later intruded the southern sediments the period of diastrophism may be referred to as Algoman. A previous period of deformation undoubtedly occurred at the time of the Laurentian intrusions into the Keewatin. There is evidence in many regions that structures then developed also had an easterly trend, but here they seem masked by younger structures, and details as to their nature are not fully known.

AGE OF THE STRUCTURES IN THE AREA

Under Lawson's and Grout's interpretation of the structure of this area, the northerly trending folds of the Keewatin and Steep Rock Lake series must have been produced some time after the deposition of the latter and before the Southern Sedimentary (Seine) series came into being. The latter were folded at a still later time with axes striking east and west and then intruded by Algoman granites.

Under the interpretation of Tanton, the Southern Sedimentary series are pre-Keewatin or Coutchiching. The Keewatin and older sediments must have suffered severe east-west folding shortly after Keewatin time, then erosion, to lay bare the vertical contact between the Keewatin and sediments on which conglomerates correlated with those of the Steep Rock Lake series (Lower Huronian?) were laid down. After Lower Huronian time folding again occurred during which the conglomerate mentioned was infolded parallel to the contact of Keewatin and Coutchiching, and at the same time the discordant Steep Rock Lake folds were probably formed. The existence of a fault along the Keewatin contact, as noted above, is required to explain why these younger folds are not imprinted as cross-folds on the supposedly older rocks to the south.

Under the new hypothesis proposed herein, the discordant folding of the southern and Steep Rock Lake sediments and the faulting are referred to one period of deformation, which is post–Steep Rock series in age. The discordant structures, then, cannot be used to infer differences in age of the various rock formations. The southern sediments may be pre-Keewatin or post-Keewatin, but are not necessarily much older or younger than the Steep Rock Lake series. The relationship in time and place of the southern sediments and the structures, if anything, favors a post-Keewatin age. A review of the evidence as to age of the southern sediments follows.

THE AGE OF THE SEDIMENTS—COUTCHICHING OR SEINE?

The Southern Sedimentary series has been considered of two ages, Coutchiching (pre-Keewatin) or Seine (post-Keewatin and post–Steep Rock Lake series). The proof presented by Tanton[1] for a pre-Keewatin age hinges largely on the fact that the sediments ap-

[1] "Recognition of the Coutchiching near Steep Rock Lake," *op. cit.*, pp. 44–48.

pear to dip under the Keewatin, and that a conglomerate of post-Keewatin age lying along the Keewatin-sediment contact near Jackfish Lake is unconformably above the finer sediments and was infolded with the older rocks at a date later than the main folding of the southern series and Keewatin. This conglomerate has been correlated with the Falls Bay conglomerate of the Steep Rock Lake series. Lawson[1] and Grout,[2] on the other hand, interpreted the conglomerate as conformable with the finer sediments to the south, and with other evidence considered it as proof of a post-Keewatin age for the southern (Seine) series. The evidence of the conglomerate will be dealt with first.

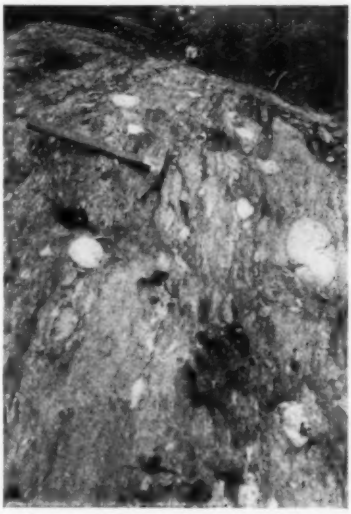

FIG. 8.—Photograph of conglomerate occurring northwest of Jackfish Lake.

EVIDENCE OF CONGLOMERATE NEAR JACKFISH LAKE

The small conglomerate mass (Fig. 8) occurs along the Keewatin sediment contact, 1½ miles north and west of Jackfish Lake. A detailed map of the conglomerate mass is given in Figure 9. It will be noted that except at the northeast corner the conglomerate is completely isolated from both the Keewatin and the main sediments on the south, by either drift or swamp. On the north of the main conglomerate bed is a band of massive gray arkosite; on the northeast are two other narrow bands of conglomerate interbedded with greenish-gray schists (slates or graywacke). On the southwest side similar green (graywacke) schists are drag folded with the main conglomerate. To the east the conglomerate lens extends along a steep hillside and becomes gradually more and more schistose until even the pebbles have disappeared in a gray sericite schist. To the west across the

[1] *Geol. Surv. Can. Mem. 40* (1913), p. 65. [2] *Op. cit.*

swamp no conglomerate was found adjoining either the Keewatin or sediments, but both of these are drag folded and contorted. The general strike of the conglomerate and associated finer clastics does not differ much from the general strike of the main sedimentary group. The dip of both is essentially vertical, and both have the same degree of schistosity.

At the northeast corner the actual contact between Keewatin and the conglomeratic bands may be observed. Here the contact is in the

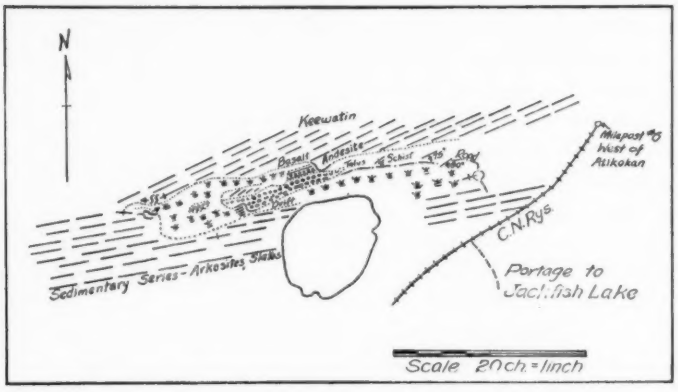

FIG. 9.—Map showing conglomerate at contact of Keewatin and Sedimentary series in the vicinity of the portage from the Seine River to Jackfish Lake.

nature of a drag fold which appears to be reflected in the conglomerate on its southern contact. The relation to the Keewatin is distinctly unconformable and discordant. The unconformable relation of the conglomerate to Keewatin is of course further shown by the basic pebbles derived from the latter. That the contact is faulted is supported by the variation of the Keewatin from basalts to more acidic flows along the contact, as already noted.[1]

The relation of the conglomerate to the main sedimentary group on the south is not so clear. A contact of conglomerate and greenish-gray schist or graywacke shows a perfect drag fold on the southwest side, the pebbles in the conglomerate being drawn out in the folding. The schistosity cuts through both schist and conglomerate, and the

[1] Tanton, "Recognition of the Coutchiching near Steep Rock Lake," *op. cit.*, p. 46.

fold pitches steeply east. Near by, small faults occur between green slaty beds and conglomerate. Between the conglomerate and the finely bedded arkosites and slates on the south is a sharp gully 30 feet wide.

Within the conglomerate and associated beds no tops could be determined. The mass as a whole has not a definite synclinal structure, which one would expect if it is younger than the sediments to the south and was actually infolded at the contact. Tanton has indicated that the sediments on the south dip under the conglomerate and Keewatin. This could not be checked by the writer, but holds true a short distance east of the railway. About 5 chains south of the conglomerate, one bed was found with an apparent top on the south.

Abundant evidence has been presented that the main Keewatin sedimentary contact is a faulted one. It is believed the conglomerate is of a general wedge shape lying along this major fault plane. The lack of any synclinal structure in the conglomerate, its very local occurrence, and its highly sheared nature on the south and east point to this conclusion. Thus the conglomerate mass as a whole may appear structurally unconformable to the sediments on the south, but any discordance may be due to faulting rather than to differences in age. The lithological similarity of the conglomerate and finer sediments suggests a similar age. Positive proof of this age must rest on the finding of the conglomerate and finer sediments together where they are not faulted. It is clear that the evidence of the conglomerate is of questionable value as regards the age of the adjacent finer sedimentary rocks.

Tanton[1] again has noted briefly the occurrence of other conglomerates near Atikokan which seem to link the Jackfish Lake mass with the Steep Rock Lake conglomerates. These were not studied by the writer. It was reported that they lie on the north of the Atikokan River within the Keewatin. Such an occurrence still does not prove that these conglomerates were not formerly connected with the finer sediments to the south. Details of their structure are not sufficient to show that all the conglomerates were once continuous with the Steep Rock Lake series.

[1] *Ibid.*, p. 48.

THE SIGNIFICANCE OF FAULTING

Since the contact between the Southern Sedimentary series and the Keewatin and post-Keewatin conglomerate is faulted and since the steeply folded sediments and their axial planes are truncated in places by the fault, it is entirely possible that anticlines and synclines may alternate along the contact, especially since the folds seem fairly closely spaced. The fact that different geologists have found the beds apparently dipping both under and over the Keewatin on the north supports this contention. Hence, the actual dip of the beds with respect to the Keewatin indicates nothing as to their age.

It is clear that definitely to prove the age of the Southern Sedimentary series it must be found in a proved unfaulted condition adjacent to the Keewatin. From the nature of the faulting, however, it is possible to state the probabilities in the case.

The major structural features of the area and vicinity, other than those of definite Laurentian age, have been accounted for by one general period of deformation, the time of which is fixed as later than the deposition of the Steep Rock Lake series (Lower Huronian) and preceding by a short interval the invasion of the southern Algoman granites. It is true that rocks as old as Keewatin, at least, have participated in this deformation, and it cannot be denied that if pre-Keewatin sediments were present they too would be affected. The association of the southern sediments with this folding and no other, however, suggests a post-Laurentian age.

Consider the faulted nature of the Jackfish Lake conglomerate and the southern sediments. If the two represent near-shore and offshore phases, respectively, of one age of sediments, the faulting required to bring the two together in their present form is not excessive. To assume, however, that the finer sediments are pre-Keewatin requires either a much greater amount of displacement along the fault, or, if the conglomerate was laid down on the eroded contact of the sediments and Keewatin, the folding of the southern series must antedate the faulting by at least one and possibly two geologic periods. In the first case it has been shown that the fault is not a great overthrust from the south but more of a horizontal shear. In the second case all of the structures may be related to one major period of deformation. The probability, then, is that the Southern Sedimentary series is post-Keewatin as is the Jackfish Lake conglomerate.

THE EVIDENCE OF INTRUSIVES

The Southern Sedimentary series is intruded by red biotite granite on the south. The age of this granite depends in part on the age of the sediments. It has been placed as Algoman (post-Laurentian) by Lawson.[1] The granite intruded the sediments after they were folded to essentially their present vertical position. The time of intrusion, however, was not necessarily much later than the folding, and it is well known that many granite batholiths probably owe their intrusion to the same causes which produced intense folding of the intruded rocks. The folding and faulting have been related to a period between the deposition of the Steep Rock Lake series and the invasion of granite. The granite, therefore, appears to be practically of the same age as the deformation, or Algoman. It is true that post-Keewatin granites might invade pre-Keewatin sediments; but, it should be noted, widespread Laurentian granites occur immediately to the north of the great Southern Sedimentary series, and it is remarkable that none of them is found cutting the supposedly pre-Keewatin sediments.

Again, in the Keewatin, immediately on the north of the sedimentary contact, in the Sapawe Lake area are abundant small lenticular intrusions of much-altered and sheared diorite and gabbro. None of these appears in the sediments and, since they are clearly post-Keewatin, their absence south of this contact suggests that the sediments were deposited after their intrusion.

RELATION OF THE SOUTHERN SEDIMENTARY SERIES TO THE COUTCHICHING OF RAINY LAKE AND THE KNIFE LAKE SLATES OF MINNESOTA

The Southern Sedimentary series has been traced by Lawson and Grout from the Steep Rock and Sapawe Lake area to Rainy Lake. At East Shoal Lake, in the latter area, only a brief examination of the sediments by the writer was possible. Here on the north, Lawson's upper or Seine series lies on both Keewatin and Laurentian, is steeply folded into synclines, and contains large conglomerate, quartzite, and slaty beds (Fig. 10). It is separated from the older (?) "Coutchiching" series on the south by a band of chloritic igneous schists, interpreted as Keewatin. Farther west they are contiguous.

[1] *Geol. Surv. of Can. Mem. 40* (1913), pp. 103–8.

In most places the contact between the two series is highly schistose and generally covered. Lawson holds that the latter dip under the Keewatin; Grout, that the reverse is true. All the rocks strike easterly. It is not definitely known that faulting has occurred here, but schisted and buried contacts suggest this possibility. The differences in lithology in the two groups are more one of size of grain than of quality and may be explained as well by their position relative to the shore line at the time of deposition as by differences in age. Conversely, if the finer-grained phases of both series suffered the same

FIG. 10.—Photograph of steeply dipping "Seine" series at East Shoal Lake, Ontario

amount of metamorphism they would not be distinguishable. The upper or Seine series on the whole is the less metamorphosed of the two, as evidenced by the preservation in quartzites of beautiful cross-bedding. This may be due to the presence of more competent beds in the Seine series or to protection from the full intensity of shearing movements, as well as to differences in age.

Comparing the Rainy Lake and Steep Rock–Sapawè Lake areas, the writer can find no difference between the main sedimentary series of the eastern area and Lawson's main belt of Coutchiching. The Jackfish Lake conglomerate resembles the Seine conglomerate of Shoal Lake, and, as Tanton has noted, the Steep Rock Lake conglomerate also. It is possible, then, that the conglomerate at Jackfish Lake is really a faulted fragment of the Seine conglomerate. The possibility that the larger sedimentary group called Coutchiching is

the same in age as both conglomerates cannot be denied on lithological grounds. Further detailed mapping between the two areas may bring together the present opposite views held as to the structure, especially since faulting will account for the apparent contradictory observations. No new data have been gathered with regard to other occurrences of Coutchiching in Rainy Lake.

Continuing west and south, Lawson shows the Coutchiching extending into Minnesota. Grout has traced these sediments southward to a similar group of sediments known as the Lower-Middle Huronian and composed largely of the Knife Lake slate series, which are definitely above the Keewatin. There has as yet been no evidence produced to question the superposition of the Knife Lake slates above the Keewatin. If this correlation of Grout's be established, the balance of evidence supports by far a post-Keewatin age for the larger portion of the sediments placed by Lawson and Tanton as Coutchiching. The Knife Lake slate series was laid down unconformably upon the Keewatin following a period of erosion, though both were later closely folded. The suggestion by Bruce that in Archean times there may have been sedimentation going on in one area, volcanic extrusions in another, while in adjoining areas the reverse order of events occurred may still be applicable to the Minnesota (Vermilion) and Rainy Lake areas, depending on the amount of pre-Keewatin sediments that may be recognized finally.

SUMMARY AS TO PRE- OR POST-KEEWATIN AGE OF THE SEDIMENTS

1. The sedimentary series as shown by Tanton appear to dip under the Keewatin lavas and therefore to appear older than the Keewatin. Since this contact is faulted, and since the sediments may locally dip away from the Keewatin, their apparent dip cannot be considered as proof of their age.

2. The post-Keewatin conglomerate near Jackfish Lake was considered as lying across the contact of the Keewatin and sediments, unconformably above both. Re-examination of this occurrence fails to show evidence of an unconformity between the conglomerate and finer sediments. Lithologically the latter cannot be distinguished from fine-grained layers within the conglomerate mass. Moreover, it is extremely difficult to conceive how post-Keewatin conglomerates

could come to their present position between pre-Keewatin sediments and Keewatin lavas simply by infolding. It is more probable that faulting alone explains their structure. The faulting required to bring Coutchiching sediments up against post-Keewatin conglomerates must have been largely a thrust of great displacement from the south. On the other hand, the faulting has been shown to be mainly of a shear type with east-west movements predominating. Much less thrusting and displacement is required if the conglomerate represents a near-shore phase of the finer sediments and both are of post-Keewatin age.

3. If the Southern Sedimentary series are pre-Keewatin, they should show the same types of folding as the Keewatin and Steep Rock Lake series. That they do not show the northerly folding of the latter is certain, and yet no explanation has been given by supporters of this age. Recognition of a fault along the Keewatin-sediment contact may be used to explain this apparent anomaly. To do this it is apparent that the folding of the Coutchiching and Keewatin must have preceded the faulting since post-Keewatin conglomerates supposedly were laid down on the eroded contact of these rocks. The folding, faulting, and intrusion of the southern sediments by granite, on the other hand, may all be related to one period of deformation, post–Steep Rock Lake series in age. This interpretation harmonizes the discordant structures to the north and south of the fault, and supports a post-Keewatin age for the sediments, especially since the actual folding of the southern series appears north of the fault and is probably slightly younger rather than older than the fault and Steep Rock Lake folds.

4. No definitely recognized Laurentian granites have been found intruding the sediments of disputed age, though granites of a later period seem abundant. Similarly post-Keewatin or Keewatin basic intrusives are found along the northern border of the sediments, but none of these has been proved intrusive into the strata.

5. The southern sediments have been traced west to Rainy Lake, where there is still some doubt as to the structure, whether faulted or not. Grout has traced these on southwest to Minnesota where he correlates them with the Knife Lake slates of Lower-Middle Huronian age.

It is concluded, therefore, on the basis of the known evidence, that

the disputed sedimentary series are of post-Keewatin age. This does not imply that Coutchiching sediments do not exist in parts of the Rainy Lake area which are isolated from the main mass under discussion.

There remains to establish the relationship between the Southern Sedimentary series and the Steep Rock Lake sediments.

POSSIBLE RELATION OF THE SOUTHERN SEDIMENTARY SERIES TO THE STEEP ROCK LAKE SERIES

The Southern Sedimentary series and the Steep Rock Lake series are nowhere definitely in contact if the conglomerate near Jackfish Lake be considered as a part of the southern sediments. The main formations are separated only by a distance of about 2 miles. The southern extension of the Steep Rock Lake series appears to have been upfaulted and eroded. It is not possible, therefore, to say definitely that it occurred below or above the southern sediments. The two groups of sediments have never been considered the same in age for two reasons. Though they both appear to contain similar conglomerates, the Steep Rock Lake series contains algal limestones; the southern series consists entirely of clastic sediments. Obviously they were formed under somewhat different environments. The Steep Rock Lake series also includes volcanic flows and probably tuffaceous green schists, and is intruded by gabbros. Neither the volcanics nor gabbros occur in the southern series. The age of the gabbro with respect to the southern Algoman intrusives is not known. These differences, however, suggest strongly some difference in age, and that the southern series is the younger, particularly since they are not intruded by the gabbros. If the gabbros are a phase of the Algoman intrusives, however, the southern series may be younger or older than the Steep Rock Lake series. From the nature of the sediments and on the supposition that the earlier were formed after the Laurentian revolution, dominantly clastic sediments would be expected, to be followed sometime later by the deposition of chemical sediments when the high lands had largely been eroded away. On this basis the southern series of clastics would be the older. No final conclusion as to the relative age of these two groups of sediments can yet be reached. The various possibilities are here suggested in the hope that further field work will uncover the required information.

VERTEBRATE FOOTPRINTS FROM THE RED-BEDS OF TEXAS. II

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ABSTRACT

The Castle Peak, Permian, footprint fauna has already been shown to contain representations of several new genera and species of ichnites indicating the presence of small branchiosaurian and microsaurian amphibians and reptiles of a varanoid type. Trails of insects, myriapods, borings, and traces of unrecognized form, as well as abundant weather markings, make the deposit near Merkel, Texas, one of exceptional interest.

The present paper is a continuation, describing new facts about known species, discussing new species, and announcing the recognition of a species described by Gilmore from the Grand Canyon Permian. A two-toed saltatorial reptile is of interest.

INTRODUCTION

While engaged in writing the first account[1] of ichnite species found at Castle Peak, 10 miles due south of Merkel, Texas, I wished for a closer personal acquaintance with this unique Red-bed deposit in order to search out additional information concerning species imperfectly represented in existing collections, as well as to secure material for additional species which from fragmentary indications actually existed at Castle Peak. Happily, my desire was realized by aid from the Department of Geology and Paleontology, University of Chicago, and a collection was made which contains the material described below. This consists of notes on previously described forms and the descriptions of new forms.

The deposit of shale-bearing footprints, locally known as "frog tracks," has been known for more than a quarter of a century. The important historical details are given in my first article, and need not be repeated here. The deposit has not yet been fully exploited, and much remains to be done.[2]

FOOTPRINT LOCALITY

Castle Peak is a prominent feature of the landscape south of Merkel, but I was surprised to find other similar buttes, isolated to a

[1] "Vertebrate Footprints from Texas Red Beds," *Amer. Jour. Sci.*, 5 Ser., Vol. XVII (1929), pp. 352–68.

[2] An illustrated account of the footprint locality is given in the *Scientific Monthly*, Vol. XXX (1930), pp. 50–58.

FIG. 1.—A slab of shale showing the effects of a slow-drizzle run-off. These markings in Triassic rock of Massachusetts were named by Hitchcock *Aenigmichnus multiformis*, who regarded them as annelid trails. Specimen in the possession of Dr. F. C. Clark, Santa Monica, California. Natural size.

certain degree from the extensive table-land, capped with resistant Cretaceous rock, which stretches for miles toward the west. Whether the track-bearing shales occur elsewhere than at Castle Peak may be determined later.

The gully in which the tracks are most abundant does not head from the peak at all, but comes in from the west. It is about 20 feet deep just before it joins the main gully, and its steeply sloping banks are liberally covered with slabs of variegated shale bearing the footprints. The shale bed lies on top of a red soft shale and, breaking off from the parent-bed in blocks of irregular shape, splits into thin slabs as the blocks weather out. The track-bearing bed is still extensive and lies close to the surface over some hundreds of square yards. One block of shale, when split into thin slabs, yielded, within a thickness of 8 inches, five successive layers of tracks. The deposit is easily reached, and one may camp within a few yards of the gully.

The footprint bed at Castle Peak shows deep sun-cracks which have divided the entire area into columns of mud shale of from 8 to 12 inches in diameter. Careful examination of the layers of one of these columns shows tracks and trails at several levels. Within the second level there were preserved imprint and obverse of a forefoot track of *Varanopus palmatus* and an imperfect track of *V. impressus*. The next lower level preserves imperfect tracks of several vertebrate species, too imperfect for exact identification. Another subjacent level presents numerous tracks of the common species, *Microsauropus acutipes* Moodie, with numerous sharply marked grooves caused by the tail drag through the soft mud. One such groove, slightly curved, presents a length of 75 mm. A still lower level shows a clear, large, undetermined trail of some invertebrate which had wallowed its way through the soft mud. These facts lead us to believe that the entire thickness of the bed represents deposition during a single season. The fact that the sun-cracks cut the entire bed lends additional favor to this view.

The following species of vertebrate ichnites were characterized in my first paper: Amphibia, Caudata, *Erpetopus willistoni;* Microsauria, *Microsauropus acutipes*, *M. clarki;* Reptilia, *Varanopus curvidactylus*, *V. impressus*, *V. palmatus*, *V.*(?) *elrodi*. The following new species are indicated by footprints recently collected: Am-

phibia, Microsauria, *Microsauropus orthodactylus*, *M. parvus;* Reptilia, *Varanopus didactylus*, *Solidopus perissodactylus*, *Laoporus wyldei*, *L.* sp. indet. Species previously known: Reptilia? *Hyloidichnus bifurcatus* Gilmore (Grand Canyon).

All specimens are from the type locality, Castle Peak, in the Valley of the Clear Fork, 10 miles due south of Merkel, Taylor County, Texas. The horizon is the upper Clear Fork, Permian.

FIG. 2.—Portion of a complete trackway of *Microsauropus acutipes* Moodie, the commonest species of the Castle Peak fauna. Specimen is the property of the Los Angeles Museum. ×¾.

NOTES ON PREVIOUSLY DESCRIBED SPECIES

Microsauropus acutipes MOODIE

This little microsaur left tracks enough in the Castle Peak shale beds to represent 80–85 per cent of all footprints found at the locality. A slab containing an interesting trackway, measuring 7×10 inches, is the property of the Los Angeles Museum.

An exceptionally perfect trackway, with tail drag (Fig. 2), gives an opportunity for determining the length of the step and the nature of the trackway. The tail drag is practically continuous over a distance of 120 mm. The length of the step from the tip of the toe of the left hind foot to the heel of the foot ahead is 52 mm. The stride is 62 mm. long.

Varanopus impressus MOODIE

This species is still imperfectly known, but I am able to add something to our knowledge of these odd footprints by the description

and illustration of a slab (Figs. 3–4) secured from the Castle Peak beds after my first paper had been accepted for publication.

Two impressions, one of the right hind foot and one of the left hind foot were examined. The length of the *step* is 175.5 mm. The tracks indicate three toes, impressed deeply into the soft mud. In fact, the mud was so soft that no details of the toes are preserved. There seems to have been no prominent heel pad. The greatest length of the right footprint is 50 mm., and the breadth, 38 mm.

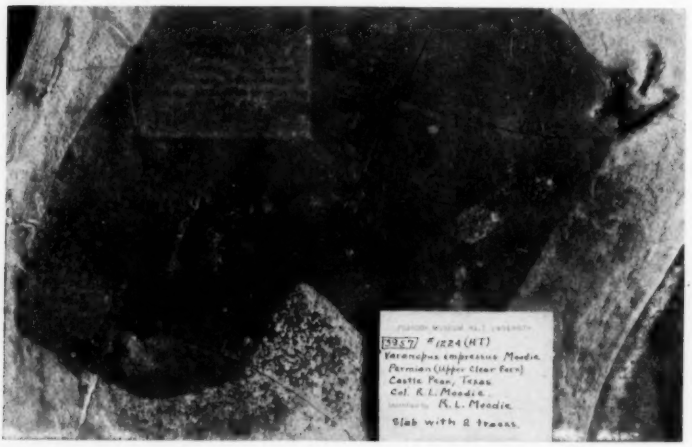

FIG. 3.—Two footprints of *Varanopus impressus* Moodie, representing a three-toed reptile. The distance from the heel of the left foot to heel of right foot is 175.5 mm. This is termed the "step," as distinguished from the "stride," which is the distance between impressions of same foot. No. 1224, Peabody Museum of Yale University. Photograph from R. S. Lull. $\times\frac{2}{3}$.

Additional information of this species is obtained from a single, almost perfect, track in the middle of a slab measuring 10 inches in diameter; No. 2304, Walker Museum (Fig. 5). The under surface of the toes was apparently lobated, suggesting the fatty pads of some modern birds. There are no evidences of scales. The middle toe, which is the longest, measuring 40 mm., is distinctly curved to the left.

Varanopus palmatus MOODIE

Although a number of additional tracks of this reptile, the largest in the fauna, were found, I am unable to add a great deal to what is already known. A large slab containing imperfect tracks, one on each edge, reveals a step of over 200 mm.; No. 2319, Walker Museum. An unusually perfect imprint of the right forefoot, both imprint and obverse, shows that this species had high, thin digits, of which there are four in the hand. The total length of the track is about 75 mm., and the width, 50 mm.

FIG. 4.—Impression of right foot of *Varanopus impressus* Moodie. No. 1224, Peabody Museum of Yale University. Photograph from R. S. Lull. Slightly more than natural size.

FIG. 5.—An almost perfect track of *Varanopus impressus* Moodie, showing lobations of the under surface of the toes. No. 2304, Walker Museum. Natural size.

The largest digit presents a length of 35 and a width of 14 mm. There is a sharply defined imprint of a callous pad on the palm, not quite so large as the one described for the foot. A shallow imprint of the entire palm measures about 30 mm. in diameter. The borders are not very sharply defined.

Hyloidichnus bifurcatus GILMORE

It is a matter of the greatest interest to announce the discovery of Gilmore's species *Hyloidichnus bifurcatus*[1] in the Castle Peak fauna.

[1] C. W. Gilmore, "Fossil Footprints from the Grand Canyon: Second Contribution," *Smithson. Misc. Coll.*, Vol. LXXX, No. 3 (1927), p. 51.

The evidence consists of incomplete tracks, but the specific characters of the tracks are so clear that I have not the slightest hesitancy in identifying the Texas ichnite as a representative (Fig. 6). No species of the Grand Canyon Permian fauna is more sharply marked, and identification is sure.

The Castle Peak specimen, No. 2307, Walker Museum, comprises the imprints of the right pes. The imprint of the digit (IV?) near the left edge of slab measures 22 mm., which is somewhat less than Gilmore's type. Digit V (pes), which measures 11 mm., is more curved outward than the Grand Canyon specimens. The tips of all the digits in the specimen from Castle Peak are bifurcated.

FIG. 6.—Imperfect, yet quite characteristic, tracks of *Hyloidichnus bifurcatus* Gilmore are found on the left of the figure. The division of the terminal digit is most clear near the extreme left of the figure. No. 2307, Walker Museum. The worm trails, with castings, on the right are undetermined. ×⅔.

HORSESHOE-SHAPED IMPRINT

Curious tracklike depressions, called by Hitchcock *Hoplichnus equus*, are described and figured by Gilmore[1] from the Permian beds of the Grand Canyon.

I wish to record (Fig. 16) the presence of such markings in the Castle Peak beds in Texas. The single example shows a width of 10 mm. and a length of 12 mm. I am unable to offer any idea of the nature of this imprint. Gilmore's discussion is pertinent here.

NEW PERMIAN ICHNITE SPECIES

Microsauropus parvus, N. SP.

Holotype.—No. 2301, Walker Museum. A slab, measuring 7×8.5 inches, showing partial trackway with sharply incised imprints of fore and hind foot. *Paratype.*—No. 2306, Walker Museum. A slab

[1] C. W. Gilmore, "Fossil Footprints from the Grand Canyon," *ibid., Smithson. Misc. Coll.*, Vol. LXXVII, No. 9 (1926), pp. 37–39, Fig. 23.

of thin shale, measuring 4.5×3 inches, showing part of trackway, with toe drag. Associated with myriapod trails. *Claw marks* of this species on slab No. 2313.

Description.—The smallest species of the Castle Peak vertebrate ichnite fauna is represented on three slabs in both imprint and obverse, showing nature of hand and foot and trackway, with length of step and stride (Figs. 7, 8, 9). The relationship with the species of

FIG. 7.—Holotype *Microsauropus parvus*, n. sp. No. 2301, Walker Museum. Natural size.

Microsauropus is quite clear, and this new species *M. parvus* is related rather closely with the common species, *M. acutipes* Moodie. The new species, *M. parvus*, differs from the genotype, *M. acutipes*, in its small size, greater proportional width, clear imprint of sole, and straighter digits. The digits of *M. parvus* show a sharp angulation in each digit, more acute than in *M. acutipes*.

On the *holotype slab* the *step* measures about 20 mm.; and the *stride*, measuring from the tip of the toe of the left hind foot to the heel of the right hind foot, is 42 mm.

On the *paratype* No. 2306, *M. parvus*, the *step* measures on the right 39 mm. and on the left 35 mm. The *stride*, measuring from the toe of the right hind foot to the heel of the left hind foot, is 62 mm. The step and stride are not readily ascertained on the type slab, but they seem to be shorter. It is apparent that the length of the step and stride are subject to emotional variation, being longer under stress of excitement.

FIG. 8.—No. 2306, Walker Museum, showing details of tracks, *Microsauropus parvus*, n. sp., the smallest of the Castle Peak fauna. Natural size.

FIG. 9.—No. 2313, Walker Museum, a small slab of shale exhibiting claw markings of a small microsaur, possibly *Microsauropus parvus*, n. sp. There are no tracks clear enough for exact identification. $\times\frac{3}{5}$.

Claw marks, apparently of this species, No. 2313 (Fig. 9), made on partially dried mud, indicate that this microsaurian species was very active—a characteristic of many of these small, reptile-like amphibians. Measurements made of the left hind foot of *Microsauropus parvus*, n. sp., show the width of the sole to be 2 mm.; maximum length of foot, 6 mm.; maximum width of foot, 5 mm.;

length of digit I, .75 mm.; II, 3 mm.; III, 3.75 mm.; IV, 2.50 mm.; V, 1.75 mm. Measurements made of the right hand of *M. parvus*, n. sp., show the maximum width of right hand to be 5 mm.; maximum length of right hand, 5.25 mm.; length of digit I, 3 mm.; II, 3.50 mm.; III, 4.50 mm.; IV, 1.75 mm.

Microsauropus orthodactylus, N. SP.

Holotype.—No. 2308, Walker Museum. A slab of green-and-red-mottled shale, measuring 5×7 inches, and consisting of a series of footprints of an imperfect trackway. Both imprint and obverse are preserved. *Paratype.*—No. 2315, obverse and imprint. *Specific characters.*—Footprints with straight toes.

Description.—This is the fourth species to be assigned to the genus, *Microsauropus*. The known species occur only at Castle Peak. The group is characterized by four digits on the manus and five on the pes; by sharp claws on all feet; by slender digits and active habits, as indicated by portions of trails made by the small microsaurs, none of which, as far as is known, exceeded 10 inches in length. The distinguishing characters of the species are the long, narrow foot; the straight toes; the small manus, and larger pes; the toe drags in semicircular fashion; and the relatively wide (35 mm.) trackway, with no evidence of a tail drag. The species differs from *M. acutipes* Moodie in its straighter, more slender digits. *M. acutipes* may always be distinguished by the sharp angulation in its digits at the ungual phalange.

The *holotype*, No. 2308, Walker Museum, shows in splendid fashion (Fig. 10) a portion, 6 inches in length, of an unusually well-preserved trackway. The *paratype*, No. 2315, Walker Museum (Fig. 11), shows tracks of *M. acutipes* and *M. orthodactylus*, with exceptionally clear, semilunar markings of the toe drag of the latter species. The *stride*, measuring from heel of right pes to the heel of right pes, is 46 mm. The distance from toe of right pes to toe of left pes, is 77 mm. The width of the trackway is about 35 mm. The width of the imprint of the manus is 7 mm.; the length is 6 mm. Digit I of left manus measures 4 mm.; digit II measures 5.5 mm.; digit III measures 5 mm. I was unable to find a manus imprint showing digit IV. It is possible that this creature's manus possessed

only three digits. No imprint of the palm is preserved. The width of an imprint of the pes is about 8 mm.; its length, 16 mm., with a short but wide heel imprint. Slab No. 2315 shows digits I and V to be less than 2 mm. in length. Digit II measures 12 mm.; digit III measures 8 mm.; digit IV is about 5 mm.

Varanopus didactylus, N. SP.

Holotype.—No. 2316, Walker Museum. A slab on which there are obverses of several footprints. *Paratype.*—No. 2310, Walker Museum. A slab of shale, 10 inches in diameter, containing at the center

FIG. 10.—The holotype of *Microsauropus orthodactylus*, n. sp. No. 2308, Walker Museum. Imprint and obverse of tracks, showing front and hind foot, on slab of shale measuring, 5×7 inches.

a single, clear obverse of a left hind foot. Another track bears the number 2309.

Description.—There are numerous specimens of an unknown species which may be assigned to the genus *Varanopus*. This species, which may be termed *didactylus*, represents a very odd vertebrate, with a track of only two toes, one of which is quite short. Different slabs show both imprint and obverse.

The *holotype*, No. 2316 (Fig. 12), shows four distinct tracks, and parts of others, all in obverse, and all of about the same size. Apparently all of them are tracks of a right hind foot. These tracks all present essentially the same features: i.e., a long, slightly curved toe, and a very short one.

The *paratype*, No. 2310, shows an almost perfect track of what I take to be the left hind foot. The large toe, which is decidedly

FIG. 11.—No. 2315 A, Walker Museum, bearing tracks and toe-drag markings of the new species *Microsauropus orthodactylus*. Typical tracks are to be seen on the right near the edge of the figure, about two-thirds down. Tracks of the common species *Microsauropus aculipes* Moodie are to be found in the lower one-third of the figure. Myriapod trails also occur. $\times\frac{3}{4}$.

curved outward, has a length of about 60 mm., and a maximum thickness of 10 mm. near the base. The shorter toe measures scarcely 20 mm.

One track on another slab, associated with numerous footprints of *Microsauropus acutipes*, measures only 40 mm. in length, but otherwise presents typical characteristics. In no case have I been able to determine the stride, or trackway of this odd vertebrate ichnite species. The form is, as far as I know, without parallel in the field of ichnology.

GENUS *Laoporus*, LULL

This genus is indicated possibly by a single impress of a five-toed, left hind foot of a species larger than either of the two already assigned to the genus. It is with reluctance that the new form is ascribed to the Grand Canyon genus,[1] but I do not feel justified in establishing a new genus on a single footprint, in the absence of such important data as length of stride, width of trackway, and the tail drag.

FIG. 12.—Holotype No. 2316, Walker Museum, representing the new species, *Varanopus didactylus*, the oddest of all the ichnite species from Castle Peak. The four tracks represented are in obverse. ×½.

Gilmore[2] gives the following definition of this genus:

> Quadrupedal, semiplantigrade, with four digits in manus and five in pes; fifth toe often not impressing. Lateral digits always shorter than median pairs. Sole broad, digits usually short. Feet usually grouped in pairs with front foot always placed in front of hind.

The described specimen shows all five toes sharply imprinted, with non-predatory claws. The first digit is the longest of the five. This character alone would seem to exclude the new species from *Laoporus*, but it will be left there until further evidence is

[1] R. S. Lull, "Fossil Footprints from the Grand Canyon of the Colorado," *Amer. Jour. Sci.*, Vol. XLV (1918), pp. 337–46.

[2] C. W. Gilmore, *op. cit.*, 1927, p. 17.

forthcoming. Immediately below this track, within one-twelfth of an inch, are other tracks, but they cannot be disclosed for fear of injuring the five-toed track. The slab contains imprints of two other species.

Laoporus wyldei, N. SP.

Holotype.—No. 2300, Walker Museum. Consists of clear, five-toed impress of left hind foot impressed on a slab of reddish shale measuring 120×120 mm. (Fig. 13).

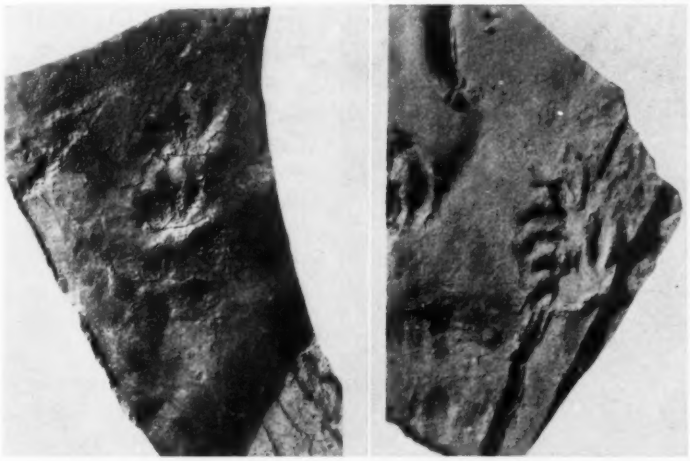

FIG. 13.—Two species of the Grand Canyon genus *Laoporus* Lull.
Left, Holotype specimen, No. 2300, Walker Museum, *Laoporus wyldei*, n. sp. impress of left hind foot. ×¾.
Right, *Laoporus*, sp. indet., No. 2305, Walker Museum. ×¾.

Description.—Five toes sharply curved outward. Claws distinct, non-predatory, but sharp-pointed. A smooth ridge of mud 12 mm. in length had been forced up between the bases of digits I and II. A similar ridge 7 mm. in length occurs between the terminal parts of digits IV and V, indicating separation of toes. Digit I lies in a straight line from the right heel pad, with claw turned to the left. A slight swelling at the base of all five ungual phalanges. Heel pads low and smooth, scarcely to be distinguished from rest of sole, which

is distinctly outlined by ridge of mud, forming an irregular semicircle posteriorly. No epidermal markings. There is no marked deviation of any of the toes. Tips of all digits are progressively closer. The distance between tips of digits I and II is 14 mm.; II and III, 13 mm.; III and IV, 11 mm.; IV and V, 8 mm. Other dimensions are the greatest length of impression, which is 32 mm.; greatest width of impression, 38 mm.; greatest length of digit I, from heel to tip, 40 mm.; greatest length of ungual phalange of digit II, 6.5 mm. The impress was made in soft mud *before* sun-cracks were formed, one of which cuts across the footprint.

FIG. 14.—Holotype No. 2314, Walker Museum, representing the new genus and species *Solidopus perissodactylus*. The pes is below; the manus above. Natural size.

The present species, if it belongs at all to the genus *Laoporus*, may be distinguished from the Grand Canyon species[1] *L. schucherti* and *L. noblei* by the curved digits in *L. wyldei* and by its larger size. The width of pes in *L. schucherti* is 21 mm.; in *L. noblei*, 28.5 mm.; in *L. wyldei*, 38 mm.

The species is named in honor of Mr. Henry Wylde, of the Los Angeles Museum, who, on arriving at the deposit, made this discovery on the first slab he picked up. After

[1] Lull, *op. cit.*, 1918; Gilmore, *op. cit.*; and "Fossil Footprints from the Grand Canyon: Third Contribution," *Smithson. Misc. Coll.*, Vol. LXXX, No. 3 (1928), pp. 3–4.

the collection was all packed and we were going, he picked up the slab bearing the imprints of still another new species.

Laoporus, SP. INDET.

Two imperfect tracks of an undetermined species of Lull's genus *Laoporus* are found on a thin slab (3×6 inches) of shale No. 2305, Walker Museum (Fig. 13). I take the imprints to be tracks of the left manus and pes, measuring approximately 20 mm. in length. The *form* of the tracks suggests the Grand Canyon genus *Laoporus*, but there are no definite characters on which one might base a specific determination. My reason for mentioning this specimen is to call attention to the presence of another species of this genus in the Castle Peak ichnite fauna. The present imperfect tracks are about two-thirds the size of *Laoporus wyldei*.

FIG. 15.—A new genus and species is represented by the imprints shown on slab No. 2302, Walker Museum, but the specimen is too imperfect for characterization. ×¾.

GENUS *Solidopus*, N. GEN.

Generic characters.—Quadrupedal, semi-digitigrade. Pes one-third larger than manus. Progression almost on tips of toes. Polydactyle unguligrade. Four digits in manus; five in pes. Footprints almost circular in soft mud. Claws blunt or slightly acuminate. Stride not determined. Entirely unrelated to any of the known Permian forms.

Genotype.—*Solidopus perissodactylus*, n. sp.

Solidopus perissodactylus, N. SP.

Holotype.—No. 2314, Walker Museum. Tracks on slab measuring 5.5×11 inches. *Paratypes.*—No. 2303, Walker Museum, two tracks, small, on red shale slab, 4×6 inches. No. 2317, Walker Museum, slab measuring 6×7 inches with four imperfect tracks. No. 2312.

Description.—Quadrupedal, semi-digitigrade, progression almost on tips of toes, like modern polydactyle ungulates. Manus much

smaller than pes. Footprints almost circular. Manus with four digits, blunt-clawed; pes with five digits, claws acuminate.

On *holotype*, No. 2314 (Fig. 14), the distance between footprints is 60 mm. Imprint of left pes, width 20 mm., length 22 mm. Right manus 15×17 mm. Specimen No. 2317 shows imprint of digits only, emphasizing the ungulate progression. Specimen No. 2303 (Fig. 16), although much smaller, is assigned to this species until further information is available. The weight distributed unequally on the feet brings digit III of pes into prominence. Footprints represent an unknown type of vertebrate. Shape of ungues polyhedral or rounded.

FIG. 16.—Horseshoe-shaped depression on the right, representing Hitchcock's species *Hoplichnus equus*, the nature of which is still unknown. Same markings are recorded by Gilmore from the Grand Canyon beds. These markings may be of mechanical origin. Tracks identified as *Solidopus perissodactylus*, n. gen. and sp. No. 2303, Walker Museum. Natural size.

SUMMARY OF ICHNITE FAUNA FROM CASTLE PEAK

Aside from footprints and trails, the only other organic evidences are fragments of plants, too imperfect for identification. Invertebrate trails are abundant, representing, I should judge, more than a dozen species; but there has been no attempt to identify the forms. This is an important undertaking yet to be accomplished, and such a study will yield important information concerning upland invertebrates of the Permian.

Six genera representing distinct groups of vertebrates have been identified. These represent two groups of amphibians and the rep-

tiles. Thirteen species of footprints have been determined, and there may be that many more which are indicated by tantalizing fragments. The majority of the fauna of vertebrates is small, few of them exceeding an estimated length of 16 inches. One fairly large reptile, *Varanopus palmatus* Moodie, may have attained a length of 3 or 4 feet.

Numerous and but slightly studied weather markings are preserved in the shale with the footprints. A careful study of these markings would go far to establish the environmental conditions of the Castle Peak fauna.

DISCUSSION OF THE REVIEW OF *ANNOTATED BIBLIOGRAPHY OF ECONOMIC GEOLOGY*

WALDEMAR LINDGREN
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I have read the review[1] of the *Annotated Bibliography of Economic Geology* with interest, and the helpful suggestions contained in that review are greatly appreciated. It was not easy to obtain the money necessary for the starting of the enterprise, and discouraging suggestions were not absent. In view of that it is good to read the various approving reviews that have appeared, and improvement will surely be the aim of the editors. The extent of the literature was at first hardly realized by those who interpreted "economic geology" in a narrow sense. Naturally the arrangement of the material was not an easy problem to solve. The literature on geophysical prospecting has increased remarkably, and the issue now in press (II, 2) for the latter half of 1929 contains about 250 items. The arrangement of this section by subjects instead of alphabetically by author has already been effected by Dr. Heiland.

Practically every geological map issued contains something of economic value, and it is aimed to make this section of areal geology as complete as possible. In every section appears the difficulty as to drawing the line between "economic" geology and "pure" geology. As many papers as possible relating to that borderland, whether covering subjects of mineralogy, petrography, structural geology, and vulcanology, have been included. Were money available and were "general" geologists interested it would be possible to widen still further the scope.

Mr. Fisher suggests that since the work being published is mainly for American geologists, annotations of publications in easily available American publications might be omitted. I believe such a course would be distinctly unwise. The *Bibliography* is intended for all English-speaking geologists, not only for Americans. It is intended for

[1] D. J. Fisher, *Jour. Geol.* Vol. XXXII (1930), pp. 187–88.

those particularly who are working in the field away from libraries and complete files of periodicals. Suppose we omit the annotations for papers in the *Bulletin of the American Association of Petroleum Geologists*. Would that be fair to field men in Asia, Russia, South America, and other distant lands? There are also many geologists who desire to follow oil geology without specializing in that branch. Briefly, the *Bibliography* is not primarily compiled for the professors. They can perhaps take care of themselves, although many instances indicate that even they are not any too familiar with their literature.

The friendly reception of the *Bibliography* and the success of the sales indicate that it fills a need long felt though rarely expressed.

IMBRICATE ARRANGEMENT OF PEBBLES IN A PRE-CAMBRIAN CONGLOMERATE

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ABSTRACT

Imbricated arrangement of pebbles in several bands of a pre-Cambrian conglomerate, called the Abram conglomerate, near Sioux Lookout, in western Ontario, is described. The consistency in orientation of the imbricated pebbles in each case proves that each band is structurally a unit and that the conglomerate was fluviatile in origin. The methods of use and the limitations of the imbricate arrangement in structural mapping are discussed.

INTRODUCTION

The imbricate structure in conglomerates has been given little discussion in geological literature. The structure is a common feature in streams supplied with pebbles of tabular form. As long ago as 1893, G. F. Becker[1] noted the imbricate arrangement and advanced an adequate explanation for it.[2] Becker says,

> On beaches pebbles are sometimes imbricated for a few feet in one or another direction and sometimes lie nearly flat. The constant reversal of the currents due to breaking and retreating waves prevents any extensive methodical arrangement, and this fact is of assistance in discriminating marine gravels from river deposits.

J. Barrell[3] has noted the same arrangement and says of it, "River gravels are shingled by the currents so that the longer diameters of the pebbles dip upstream, giving a faint appearance of false bedding,

[1] G. F. Becker, "Finite Homogeneous Strain, Flow, and Rupture of Rocks," *Bull. Geol. Soc. Amer.*, Vol. IV (1893), pp. 53–54.

[2] Becker's explanation is as follows: "If a flattened pebble is dropped into a running stream, the water will exert a pressure upon the stone until its inertia is overcome, and during this time the pebble will tend to swing across the current so as to present its greatest area to the pressure. As soon as the resistance due to its inertia is overcome, the pebble will sink through the water as if the fluid were at rest till its edge touches the bottom, and it will then tip down stream, till it meets support. . . . . Many pebbles thus deposited will, with few exceptions, be inclined down stream and will rest against one another like overlapping tiles." Apparently Becker's phrase "inclined down stream" means dipping upstream.

[3] J. Barrell, "Dominantly Fluviatile Origin under Seasonal Rainfall of the Old Red Sandstone," *Bull. Geol. Soc. Amer.*, Vol. XXVII (1916), p. 357.

which on the average, unlike the false bedding of sandstone strata, dips toward the basin margin." W. A. Johnston[1] also describes this arrangement and concludes that it is most common in coarse gravels of stream origin. F. H. Lahee[2] and W. H. Twenhofel[3] summarizes the salient features of the overlapping arrangement of pebbles.

ABRAM CONGLOMERATE

The conglomerate, which the writer has chosen to call the Abram conglomerate, and in which this imbricate structure was observed,

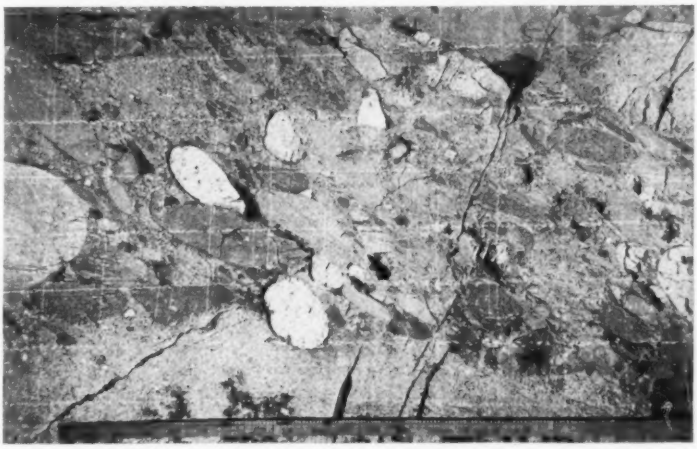

FIG. 1.—Photograph of horizontal glaciated surface of conglomerate showing the imbrication. Squares ruled on the outcrop. Each square is 2 inches on a side.

occurs in four great outcrop belts. Three of these were studied in detail by the writer, and the fourth, in the region of Schist Lake and Lake Kashaweogama, has been described by E. S. Moore.[4] The

[1] W. A. Johnston, "Imbricated Structure in River-Gravels," *Amer. Jour. Sci.*, Vol. IV (1922), pp. 387–90.

[2] F. H. Lahee, *Field Geology* (1923), p. 92.

[3] W. H. Twenhofel, *Treatise on Sedimentation* (1926), p. 158.

[4] E. S. Moore, "Lake Savant Iron Range Area," *Ontario Bureau Mines, Annual Report 19*, Part I (1910), pp. 173–93. Also "Lake Savant Area," *Ontario Bureau Mines, Annual Report 37*, Part IV (1928), pp. 53–82.

In the earlier report Moore assigns these clastic rocks to the Huronian. In the later report they are referred to the Timiskaming.

three occur near Sioux Lookout, in northwestern Ontario, on the main line of the Canadian National Railway, where it is joined by the Lake Superior Branch.[1] One belt of conglomerate is found in Grand Trunk Pacific Block 10, another on the shores of Abram Lake, and the third is best exposed between Vermilion Lake and Little Vermilion Lake in the townships of Lomond, Vermilion, Jordan, and Drayton. The band between the Vermilion lakes attains a thickness of not less than 5,300 feet and was followed continuously for some

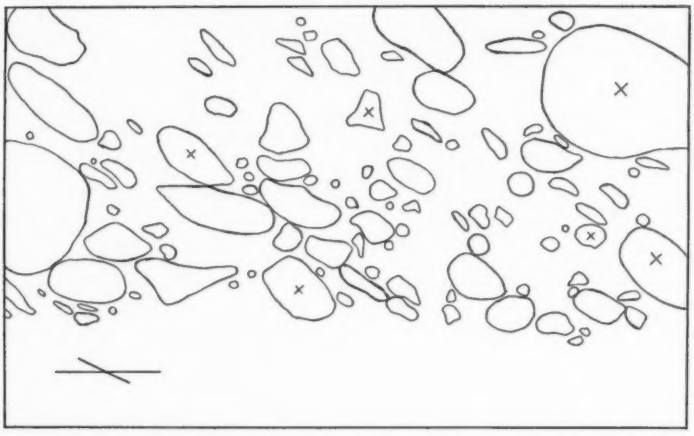

FIG. 2.—Sketch from the photograph (Fig. 1), showing the arrangement of pebbles in a boulder bed exposed in the bay of Little Vermilion Lake north of Porcupine Narrows. Scale: 1 in. = 11½ in. Pebbles marked "*x*" are granite.

15 miles along the strike. The rock is made up in varying proportions of alternating boulder conglomerates, pebbly arkosites, and thick arkosites of perfectly massive character. The band on Abram Lake, 7 miles in length, and the band in Block 10, 6 miles in length, contain a greater proportion of boulder conglomerate.

The Abram conglomerate, in all belts, contains a varied assemblage of pebbles. Granites, greenstones and green schists, felsites,

[1] W. H. Collins noted two of these belts in a reconnaissance survey of this region in 1909. See W. H. Collins, "A Geological Reconnaissance of the Region Traversed by the National Transcontinental Railway between Lake Nipigon and Clay Lake, Ontario," *Canada Department of Mines, Geological Survey Branch, Publication No. 1059* (1909).

metadiorites and metadiabases, and quartz are the most common. These vary in size up to boulders from 3 to 5 feet in diameter. The bedding in most places is vertical.

The writer noted that the strike readings obtained from the arkosite and boulder beds differed from readings obtained from the common orientation of the elongate pebbles, particularly the flat pebbles of green schist, within the conglomerate beds. A careful study proved this to be due to an overlapping arrangement of the

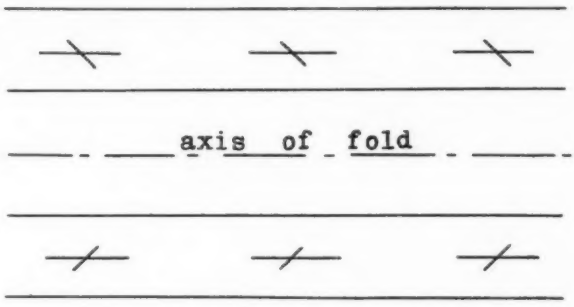

FIG. 3.—Diagram (map) showing the outcropping bands of the same conglomerate on each limb of an isoclinal fold, with the imbricate structure plotted for each.

pebbles at the time of the deposition of the fragments. The line of common orientation clearly makes an angle with the top and bottom of the boulder bed as determined by the contact with the arkosite bands above and below. This angle varies, in many cases attaining from 35° to 40°. The relations between the two were represented on the structure maps by a symbol devised for the purpose: —\—. The long line represents the true strike; the short line represents the apparent or false strike. This relationship proved useful in determining the major geologic structures, for it is clear that if the positions of the top and bottom were reversed by folding, the strike of the pebbles must show a different relation to the strike of the beds, even if the folding were isoclinal and the limbs remain parallel (see diagram, Fig. 3).

Several limitations of this method of structural mapping are at once evident:

1. If the pebbles are exceedingly well rounded no common orientation will be possible.

2. If the pebbles approach roundness the orientation will be indistinct and personal judgment will be a large factor.

3. No imbrication may have ever been present.

4. Such imbrication as may exist may be cut by the plane of the outcrop in such a way that it is not visible.[1]

5. Dynamic pressure may deform the pebbles and rotate their position so that the original imbrication is modified or lost.

6. It is possible also that the variability in direction of the depositing current will result in variable directions of imbrication. In view

FIG. 4.—Sketch showing the imbricate arrangement in a single pebble band. Little Vermilion Lake about ½ mile from Twin Falls. Scale: 1 in. = 2 ft. Shaded pebbles are greenstone and green schist; unshaded pebbles are granite.

of this fact repeated folding cannot be demonstrated by this method, but the *lack* of it alone can be shown.

Two structures, schistosity and cross-bedding, simulate the imbricate arrangement in some degree. A common alignment is developed by dynamic pressure, which is often accompanied by a granulation, squeezing, and stretching of the pebbles and the development of a schistose matrix. None of these features are associated with the imbrication described in this area. In fact, where schistosity appears in the matrix the imbricate structure is not safely used for any purpose. However, the shapes of the pebbles in true imbricate structure are those produced by water wear and not the lenticular outlines produced by compression.

Cross-bedding also resembles the imbricate structure in consider-

[1] It is to be noted in this connection that no imbricate structure would be seen on the planed edges of vertical beds if the currents producing such structures had flowed in a direction approximately normal to the present fold. The use of this structure in mapping in this region, then, depends on the fact that the currents ran obliquely across the present structures or even parallel to the fold axes.

able degree. However the arrangement of pebbles in a single lamination or band (see sketch, Fig. 4) and the high angle obtained in some cases (over 40°) will serve to discriminate these two sedimentary features.

CONCLUSIONS

Since the imbricate structure, when uniform in direction over a great thickness of conglomerate, is indicative only of river-current action, the possibilities of eolian, glacial, lacustrine, and marine origin are at once eliminated for most of the formation.[1]

The imbricate arrangement proved very useful in structural mapping when the direction of imbrication was constant or consistent. In the case of the conglomerates in question, the common orientation across the width of the bands shows that the belts have a structural unity, that is, they cannot be "closely appressed synclines" infolded with the adjacent rocks.[2]

[1] This conclusion is amply substantiated by other evidence, e.g., the great thickness is incompatible with any hypothesis of marine origin. The water-worn and water-stratified materials lead to the same conclusion and preclude the possibility of a glacial origin for the rock.

[2] This conclusion is also confirmed by other data too detailed to review here.

REVIEWS

The Coral Reef Problem. By WILLIAM MORRIS DAVIS. Special Publication No. 9. American Geographical Society. New York, 1928. Pp. 596; figs. 227.

The coral reefs of the tropical seas have been the occasion of a surprising number of theories and long-continued debate. To examine critically the various theories advanced for coral-reef origin, in order to discover which one of them, or which combination of several of them, is most successful in meeting all the facts, is the task which Professor Davis has set himself in this splendid comprehensive study.

The first chapter on observable features is introductory. The second, "Darwin's Theory of Upgrowing Reefs on Intermittently Subsiding Foundations," and the third "Extensions of Darwin's Theory," give the favored view and so in a way the key to the whole volume. In chapter 4, nine alternative theories, apart from Darwin's own alternatives, have been reviewed in an incisive manner, at once interesting and instructive to the general reader. Chapter 5 presents the glacial-control theory of coral reefs as the chief rival of the Darwinian hypothesis. Particular attention, in each case, has been given to the conditions postulated and, as far as possible, to the various consequences following therefrom.

The ultimate test of a theory is whether or not it meets successfully all the facts, particularly new or independent facts not considered when the theory was advanced. Davis believes that independent evidence as to the value of the competing theories of coral-reef origin can best be obtained, not from the reefs themselves, but rather from the physiographic features of the coasts that are bordered by fringing reefs or fronted by barrier reefs, and from the structure of elevated reefs. To marshal the testimony systematically, he has considered first certain islands of the cooler seas which were never reef-defended; then the islands of the marginal belts of the coral seas, alternately reef-defended in non-glacial epochs and reef-free in glacial epochs; and finally the continental coasts, islands, and the persistent reefs of the coral seas. The islands of the last region he has subdivided (1) according to the stage of dissection, (2) according to the kind of reefs associated with them, and (3) according to the changes of altitude (subsidence or upheaval) which they have suffered. Atolls, which afford little direct evidence, are treated last.

Wholly admirable, both in scientific analysis and effective presentation, is this treatment of the ocean in three zones—the coral seas, the

marginal belts, and the cooler seas—revealing the monographic sweep of the study which the reader cannot fail to appreciate as a model of its kind. In each chapter one sails delightfully amid the islands of far-flung seas gathering in the significant signs and diagnostic details which are later synthesized in a summary of interpretation. In these summaries the theories of weak foundation have largely faded out and the searchlights of evidence are turned chiefly on the Darwinian and glacial control theories. Darwin's theory of upgrowing reefs on intermittently subsiding foundations seems to stand the varied tests remarkably well, and the general verdict is a splendid tribute to the extraordinary vision of that wonderful man. The glacial control theory, championed by Daly, does not fare so well as a general explanation of the development of barrier reefs and atolls, though its postulated low-level abrasion during glacial epochs is here recognized as an important factor which has played its part, particularly in the marginal seas.

Davis has very ably shown in this world-wide study how many of the reef features the Darwinian theory readily explains and what a varied assemblage of independent facts serves to support it. The mass of detailed evidence brought forward and discussed is impressive and the argumentation convincing in its thoroughness. Its very breadth and completeness places any adequate discussion of it beyond the limits of a brief review. Not unnaturally, however, with increasing knowledge, certain extensions of Darwin's original theory have become necessary. The essential features of these have been contributed from time to time by various investigators, either from the consideration of Darwin's views or in independent settings. Particularly prominent have been the additions of Dana, Daly, and Davis. But never before has the full theory, with its derivatives, consequences, and extensions, supported by varied independent evidence, been presented in a composite whole, as in this volume by Davis.

The final paragraph of the present volume is such an excellent survey of the progress of this study that it is worthy of repetition here.

> Through all this period of observation and study I have therefore felt a growing admiration for the keen insight of the young naturalist of the *Beagle* and have thus come to appreciate better than ever before the calm fairmindedness with which he, in his maturer years, taught a new philosophy to an unwilling world. It has been a great pleasure to try to secure for his early-framed theory of coral reefs, which after world-wide adoption between 1840 and 1870 was so strongly objected to and even rejected by a number of later observers between 1870 and 1910, the broader consideration that it so fully deserves. The theory was only an outline in the form conceived by Darwin; for the facts of the coral reef problem were then imperfectly known, and various phases of the theory itself were left undefined. Yet, as new facts have been brought to light, it has

been most impressive to note the ease with which they have been explained by inevitable extensions of the old theory. The explanations were, indeed, latent in the theory from the beginning. The only serious exception to this statement concerns the islands of the marginal belts of the coral seas, for the explanation of which Darwin's theory must be supplemented by the wholly new process of low-level abrasion, first brought into the problem in recent years by Daly. Thus modified, the success of the old theory in explaining many more facts than those which it was invented to explain gives assurance of its being a true mental counterpart of the invisible conditions and processes of the past under which the coral reefs of today have been developed.

A bibliography of 745 titles completes this truly outstanding volume which is likely to remain, for a long time to come, the ranking work in this field.

R. T. C.

A Remarkable Ground Sloth. By RICHARD SWANN LULL. *Memoirs of the Peabody Museum of Yale University*, Vol. III, Part II (1929). Pp. 12; pls. 9.

A description of the most interesting specimen of edentate ever found on this continent—a complete skeleton of the ground sloth *Nothrotherium*, discovered in a guano-filled pit in an old crater near El Paso. The remains were in such a "fresh" condition that not only was the complete skeleton present, but also the ligaments and tendons holding the bones in their natural articulations, and even shreds of muscle and patches of skin.

Current belief as to faunal succession would make it necessary to date this specimen as early Pleistocene. But this is, as Lull states, "almost unthinkable." Taken with other recent finds, this remarkable discovery leads to the conclusion that our ideas of the vertebrate Pleistocene succession are sadly in need of revision.

A. S. R.

The Geology of Cowley County, Kansas. By N. W. BASS. State Geological Survey of Kansas, Lawrence, Kansas. Pp. 203, figs. 23, pls. 12. Geological map in color in pocket.

The chief merit of the report lies in making available considerable information upon one of the principal oil- and gas-producing areas of Kansas. It is an excellent example of the results obtained by the co-operation of the government surveys with the geological departments of private companies. Well written and organized, it deserves the use of better materials in publication.

R. E. E.